

O-FUCOSYLTRANSFERASE

BACKGROUND

The present invention relates to the field of glycosyltransferases, or enzymes which transfer sugar residues from an activated donor substrate to an amino acid or growing carbohydrate group.

Glycosyltransferases that are involved in the biosynthesis of glycoprotein and glycolipid sugar chains are resident membrane proteins of the endoplasmic reticulum and the Golgi apparatus. They are responsible for catalysis of the addition of monosaccharide units either to an existing glycan chain or to a peptide or lipid acceptor initiating a chain. Donor monosaccharides are typically utilized in activated form, either as a nucleotide sugar, e.g. GDP-mannose or, less frequently, as a lipid-linked donor, e.g., dolichol-P-glucose (Dol-P-Glc). The majority of glycosyltransferases are lumenally oriented, i.e. with the catalytic domain within a membrane-bounded compartment. Examples of lumenally oriented enzymes are galactosyltransferases and sialyltransferases. Their structure is pictorially represented in Figure 1. The enzymes are typically grouped into families based on the type of sugar they transfer (galactosyltransferases, sialyltransferases, etc.). Comparisons amongst known cDNA clones of glycosyltransferases (Paulson, J.C. & Colley, K.J., *J. Biol. Chem.* 264 (30), 17615-618 (1989), has revealed that there is very little sequence homology between the enzymes. However, as indicated by Figure 1, all glycosyltransferases share some common structural features: a short NH₂-terminal cytoplasmic tail, a 16-20 amino acid signal-anchor domain, and an extended stem region which is followed by the large COOH-terminal catalytic domain. The signal anchor domains act as both uncleavable signal peptides and as membrane-spanning regions and orient the catalytic domains of these glycosyltransferases within the lumen of the Golgi apparatus.

The means by which cells regulate the expression of specific carbohydrate sequences is of great interest because of increasing evidence that cell surface carbohydrate groups mediate a variety of cellular interactions during development, differentiation, and oncogenic transformation. von Figura, K. & Hasilik, A., *Annu. Rev. Biochem.* 55, 167-193 (1986); Kornfield, S., *J. Clin. Invest.* 77, 1-6 (1986); Munro, S. & Pelham, H.R.B., *Cell* 48, 899-907 (1987); Pelham, H.R.B., *EMBO J.* 7, 913-918 (1988); Paabo, S. et al., *Cell* 50, 311-317 (1987). It is estimated that at least one hundred (100) glycosyltransferases are required for the synthesis of

known carbohydrate structures on glycoproteins and glycolipids, and most of these are involved in elaborating the highly diverse terminal sequences. Paulson, J.C. & Colley, K.J., *J. Biol. Chem.* 264 (30), 17615-618 (1989). Among those enzymes responsible for terminal elaborations, three (3) enzymes have been of particular interest: galactosyltransferases, fucosyltransferases and sialyltransferases.

Fucosyltransferases transfer the sugar fucose from UDP in α 1-2, α 1-3, α 1-4 and α 1-6 linkages. Fucose was first identified as being present in glycosidic linkages to serine or threonine as compounds of the type Glc₁–3Fuca₁–O-Ser/Thr and Fuca₁–O-Ser/Thr in human urine and rat tissue. Hallgren, P. et al., *J. Biol. Chem.* 250, 5312-5314 (1975); Klinger, M.M. et al., *J. Biol. Chem.* 256, 7932-7935 (1981). The identification of O-linked fucose attached to a specific protein was first made by Kentzer et al. who found a residue of fucose covalently linked to a peptide derived from the epidermal growth factor (EGF) domain of recombinant urokinase. Kentzer, E.J. et al., *Biochem. Biophys. Res. Commun.*, 171, 401-406 (1990). Similar glycosylation patterns have been found in tissue plasminogen activator (tPA) (Harris, R.J. & Spellman, M.W., *Biochemistry* 30, 2311-14 (1991)), human factor VII (Bjoern et al. 266, 11051-11057 (1991)), human factor XII, (Harris et al., *J. Biol. Chem.*, 267, 5102-5107 (1992)) and vampire bat plasminogen activator, Gardell et al, *J. Biol. Chem.* 264, 17947-52 (1989). The EGF domain of human factor IX has also been indicated to have O-fucosylation, but at the reducing end of the tetrasaccharide: NeuAca₂–6Gal₁–4GlcNAc₁–3Fuca₁–O-Ser₆₁. Nishimura et al., *J. Biol. Chem.*, 267, 17520-17525 (1992); Harris et al., *Glycobiology* 3, 219-224 (1993). However, in all cases in which it has been detected, O-linked fucose is present within the sequence Cys-Xaa-Xaa-Gly-Gly-Ser/Thr-Cys. Harris et al., *Glycobiology* 3, 219-224 (1993).

EGF is a potent 53 amino acid mitogen which has its activity mediated by binding to the EGF receptor. Carpenter, G and Cohen, C, *J. Biol. Chem.* 265, 7709-7712 (1990). Regions of EGF sequence homology have been found in an every-increasing number of coagulation, fibrinolytic, complement and receptor proteins. Paathy, L., *FEBS Lett.* 214, 1-7 (1987); Doolittle, R.F., *Trends Biochem. Sci.* 14, 244-245 (1989). The EFG modules of these multi-modular proteins are not believed to interact with the EGF receptor. Rather, different properties have been ascribed to such EGF modules, including ligand binding (Appella et al., *J. Biol. Chem.* 262, 4437-4440 (1987); Kurosawa et al., *J. Biol. Chem.* 263, 5993-5996 (1988), mitogenic activity (Engel, *FEBS Lett.* 251, 1-7 (1989) and receptor recycling (Davis et al., *Nature* 326, 760-765 (1987). The EGF modules of the vitamin K-dependent coagulation proteins are required for the proper folding of adjacent modules containing γ -carboxylglutamic acid residues (Astermark et al., *J. Biol. Chem.* 266, 2430-2437 (1991), while others may simply serve as spacers between different functionally active regions (Stenflo, J., *Blood* 78, 1637-1651 (1991).

EGF domains are characterized by the presence of six (6) conserved cysteine residues that are expected to form three (3) intrachain disulfide bonds in the 1-3, 2-4 and 5-6 pattern obtained for EGF. Savage et al., *J. Biol. Chem.* 248, 7669-7672 (1973). A similar disulfide-binding pattern has been confirmed for the EGF domain of human complement protein C1s, Hess et al., *Biochemistry* 30, 2827-2833 (1991). Three dimensional solution structures of synthetic comprising individual N-terminal EGF modules of human factors X and IX have been obtained by NMR spectroscopic studies (Selander et al., *Biochemistry* 29, 8111-8118 (1990); Huang et al., *Biochemistry* 30, 7402-7409 (1991); Baron et al., *Protein Sci.* 1, 81-90 (1992); Ullner et al., *Biochemistry* 31, 5974-5983 (1992). The derived structures are almost identical to those determined for EGF (Cooke et al, *Nature* 327, 339-341 (1987) and TGF- α (Kohda et al, *Biochemistry* 28, 953-958 (1989); Tappin et al., *Eur. J. Biochem.* 179, 629-637 (1989).

There is an intense interest in the synthesis of proteins which contain O-fucose in glycosidic linkages. This is especially true in proteins with EGF domains which are O-fucosylated. In order to properly and efficiently O-fucosylate these proteins, an enzyme specific to creating O-fucose linkages would be highly desirable. However, as previous attempts to isolate and purify O-fucosyltransferase have proved to be unsuccessful, there exists a great need for highly pure, homogeneous O-fucosyltransferase as well as an efficient detection assay .

SUMMARY

The present invention describes identification, recombinant production and the characterization of novel O-fucosyltransferase enzymes. More specifically, the present invention describes the isolation of cDNAs encoding various forms of O-fucosyltransferase and to the expression and characterization of O-fucosyltransferases.

In one aspect, the present invention relates to substantially pure O-fucosyltransferase, including an amino acid sequence substantially identical to the sequence shown in Figure 12A [SEQ ID NO:2]. In the preferred embodiment, substantially pure O-fucosyltransferase is obtained from mammalian (eg, human, hamster) sources.

In another aspect, the present invention relates to a substantially pure O-fucosyltransferase which is capable of glycosylating the EGF domain of a peptide with an activated O-fucose moiety. In a more limited aspect, the present invention relates to a substantially pure O-fucosyltransferase which is capable of glycosylating the sequence -Cys-Xaa-Xaa-Xaa-Xaa-Ser/Thr-Cys-. In yet a more limited aspect, the sequence is -Cys-Xaa-Xaa-Gly-Gly-Ser/Thr-Cys-.

In a related aspect, the present invention relates to functional fragment or analog of O-fucosyltransferase including an amino acid sequence substantially identical to the sequence shown in Fig. 12B. [SEQ ID NO:9]. In a more limited aspect, this functional fragment or analog is capable of glycosylating the sequence -Cys-Xaa-Xaa-Xaa-Xaa-Ser/Thr-Cys-. In yet a more limited aspect, the sequence is Cys-Xaa-Xaa-Gly-Gly-Ser/Thr-Cys.

In another aspect, the invention relates to substantially pure DNA having a sequence substantially identical to the nucleotide shown in Fig. 12A [SEQ ID NO:1] wherein such DNA encodes a protein capable of glycosylating the EGF domain of a polypeptide. In a more limited aspect, this DNA is capable of glycosylating the sequence -Cys-Xaa-Xaa-Xaa-Xaa-Ser/Thr-Cys- In yet a more limited aspect, the sequence is Cys-Xaa-Xaa-Gly-Gly-Ser/Thr-Cys.

In yet another aspect, the invention relates to antibodies which are capable of binding to O-fucosyltransferase, including the sequence of Fig. 12A [SEQ ID NO:1]. These antibodies may be polyclonal, monoclonal, humanized, bispecific or heterospecific.

In still another aspect, the invention relates to a method of placing an O-fucose onto an EGF domain of a polypeptide. In a more limited aspect the glycosylated sequence is -Cys-Xaa-Xaa-Xaa-Xaa-Ser/Thr-Cys- In yet a more limited aspect, the sequence is Cys-Xaa-Xaa-Gly-Gly-Ser/Thr-Cys.

In still another aspect, the invention relates to a method or assay for detecting the presence of O-fucosyltransferase comprising the steps of:

- a) preparation of extract from a cell line expressing O-fucosyltransferase;
- b) first chromatography purification over an anion exchange resin and nucleotide binding resin;
- c) second chromatography purification over an acceptor substrate ligand associated with a metal chelating-agarose resin;
- d) third chromatography purification over a donor substrate analog ligand associated with agarose.

In still another aspect, the invention relates to inhibitors of O-fucosyltransferase and to a method of their use in the treatment of diseases mediated by proteins having their efficacy determined at least in part by the presence of O-linked fucose.

Other aspects of the invention will become apparent from the following detailed description and the claims.

Brief Description of the Drawings

In Figures 2-4, one unit corresponds to 1 μ mol of fucose transferred per minute.

Fig. 1 represents graphically the structure of glycosyltransferases, illustrating the catalytic domain, stem and transmembrane domain, in relation to the cytoplasm, membrane and lumen of the cell.

Fig. 2 represents a chromatograph over a DE-52/Affi-Gel blue combined column. Open circles represent protein concentration and open diamonds represent enzyme activity. At point A, the DE-52 column was detached and the Affi-Gel Blue column was washed with buffer containing 125 mM NaCl. Elution of the enzyme started at Point B, with buffer containing 1 M NaCl.

Fig. 3 represents a chromatograph over a column of affinity resin attached to the acceptor substrate, which here was Factor VII EGF-1-His₆-Ni²⁺NTA-Agarose. Open diamonds represent enzyme activity and open circles represent protein concentrations as monitored at 280 nm. At Point A and B, the column was washed with buffers containing 0.5 M NaCl and 25 mM imidazole. The enzyme and Factor VII EGF domain were eluted together at Point C with 0.3 M imidazole.

Fig. 4 represents a chromatograph over a column of affinity resin attached to a donor substrate analog, which here was GDP-hexanolamine-agarose. Open circles represent protein concentration as monitored at 280 nm, and open diamonds represent enzyme activity. The dashed line indicates the 0-2 Nm GDP gradient used for elution (monitored at 280 nm, scale not shown). After the sample was loaded, the column was washed with equilibration buffer and equilibration buffer containing 125 mM NaCl, which is represented as Point A. The elution of enzyme began at Point B.

Fig. 5 represents an SDS-PAGE gel of O-fucosyltransferase prepared by affinity chromatography. Each column shows the protein detected by silver stain in a fraction collected from the column represented in Fig. 4.

Fig. 6 represents the results of glycosidase digestion of O-fucosyltransferase. Reduced samples were electrophoresed on a 12% gel with SDS. Lane 1 is from the control reaction without glycosidases. Lane 2 is PNGase F digestion and Lane 3 is Endoglycosidase H digestion. The low molecular weight bands in Lane 2 and 3 are PNGase F and endoglycosidase H, respectively. The two outer lanes are molecular weight markers.

Fig. 7 represents a chromatograph of Factor IX EGF domain and its mutants by reverse phase HPLC. The recombinant mutants are as described in Table 2. Peaks labeled with retention times are recombinant proteins as verified by electrospray mass spectrometry. In one chromatogram all labeled peaks have the same molecular

weight.

Fig. 8 represents an LC/MS of the reaction product of O-fucosyltransferase upon the mutant EGF.AA. The reverse phase HPLC chromatogram of the non-fucosylated form is shown in Figure 7, panel A. The upper panel of Fig. 8 is the chromatogram of RP-HPLC of O-fucosylated EGF.AA. Major peaks were labeled with retention time and their corresponding mass spectra are shown in the lower panel. Major ions are labeled with their mass over charge value. The calculated molecular weights are 5817 (peaks 28.8, 29.3 & 33.0) and 5964 (peak 30.4 only).

Fig. 9 is a comparison of the amino acid sequences between a partial sequence of the isolated CHO O-fucosyltransferase and known human and *C. elegans* sequences. The N terminal polypeptide sequence of CHO O-fucosyltransferase is shaded. Human sequence is a partial cDNA of unknown protein from a myeloblast cell line and *C. elegans* gene is a computer generated coding sequence from its genome.

Fig. 10 is a northern blot for O-fucosyltransferase. The probes were taken from human KIAA sequences as indicated in Fig. 11. The molecular weight markers are given in kilobases.

Fig. 11 is the DNA sequence of human KIAA0180 first EcoR1 fragment. The first EcoR1 fragment of the cDNA contains a partial coding sequence within a complete amino terminus. The region which matched with the CHO polypeptide sequence is shaded. The two oligonucleotides used to make the probes for the northern blot (Fig. 10) are over-scored and double-underlined. The nucleotides over-scored and single under-lined were used in the PCR amplification.

Fig. 12 is the DNA sequence of human heart O-fucosyltransferase. The upper panel (A) is a compiled sequence from positive cDNA clones. The region that matches with the isolated CHO sequence is shaded. The residue "A" at position 540 of the DNA sequence (indicated by double underline) is different from that of human KIAA0180 (G at position 475 of Figure 11), however, the coded polypeptides are the same. The lower panel (B) is a comparison of O-fucosyltransferase amino terminal sequences isolated from human heart and CHO cells.

Fig. 13 represents the plasmid construct for expression of human O-fucosyltransferase. The upper panel (A) is a schematic drawing of the plasmid. The lower panel (B) is the sequence of the insert. The artificial signal polypeptide is shaded and the polyhistidine tag is double underlined. The human heart O-fucosyltransferase part is the same as described in Fig. 12.

Fig. 14 is a graphical comparison of the O-fucosyltransferase activity in 5 tested recombinant clones. The cultures were infected with five (5) purified recombinant clones and tested for enzyme activity according to the method of the invention. The cultures of uninfected cells (Sf9) were used as the control.

Fig. 15 is a 12% SDS-PAGE silver stained gel of recombinant human O-fucosyltransferase. Lane 1 contains infected culture medium. Lane 2 contains flow through fraction of Ni²⁺-NTA column. Lane 3 is the result of 25 mM imidazole wash, while Lane 4 is 0.3 M imidazole elution. The molecular weight markers are in kilodalton.

SEQ ID NO:1 is the sequenced nucleotide sequence of human heart O-fucosyltransferase which was isolated in Example 1 and indicated in Fig. 12A.

SEQ ID NO:2 is the amino acid sequence of human heart O-fucosyltransferase isolated from Sf9 cells shown in Fig. 12A.

SEQ ID NO:3 is N-terminal amino acid sequence of CHO O-fucosyltransferase shown in Fig. 12B.

SEQ ID NO:4 is the nucleotide sequence starting from bp. 4101 to 5399 and represents the nucleotide sequence depicted in Fig. 13B. This sequence also comprises the DNA insert used in the cloning and expression of human heart O-fucosyltransferase.

SEQ ID NO:5 is the full length nucleotide sequence of the expression plasmid including SEQ ID NO:4.

SEQ ID NO:6 is the amino acid sequence representing the plasmid insertion shown in Fig. 13B.

SEQ ID NO:7 is the first EcoR1 nucleotide sequence of human KIAA0180 depicted in Fig. 11.

SEQ ID NO:8 is a computer generated amino acid sequence corresponding to genomic DNA from C. Elegans depicted in Fig. 9.

SEQ ID NO:9 is the first 61 N-terminal amino acid residues of human heart O-fucosyltransferase depicted in Fig. 12B.

SEQ ID NO:10 is the nucleotide sequence of the first probe used in the northern blot hybridization of Example 1.

SEQ ID NO:11 is the nucleotide sequence of the second probe used in the northern blot hybridization of Example 1.

SEQ ID NO:12 is the first PCR primer used in the amplification described in Example 1.

SEQ ID NO:13 is the second PCR primer used in the amplification described in Example 1.

SEQ ID NO:14 is the N-terminal amino acid sequence of the polypeptide expressed in Sf9 cells shown described in Example 1.

SEQ ID NO:15 is the expressed EGF factor domain derived primary sequence used in making the acceptor analog ligand described in Example 2.

SEQ ID NO:16 is the first 1100 nucleotides which correspond to the actively expressed human heart O-fucosyltransferase shown in Fig. 12A.

SEQ ID NO:17 is the published partial human sequence of unknown function from a myeloblast cell line.

Detailed Description of the Preferred Embodiments

Definitions:

The terms used throughout this application are to be construed with the meaning typical to those of ordinary skill in the art. However, Applicants desire that the following terms be given the particular definition as described below.

The word "protein" or "polypeptide" are intended to be used interchangeably. They refer to chains of two (2) or more amino acids which are linked together with peptide or amide bonds, regardless of post-translational modification (e.g., glycosylation or phosphorylation). The term "enzyme" should also be construed interchangeably with O-fucosyltransferase.

The phrase "substantially pure" is meant to describe O-fucosyltransferase which has been separated

from components which naturally accompanied the enzyme during its production. Such production could be either from natural sources (cell lines, tissues), recombinant sources, or even synthetic such as by stepwise chemical amino acid addition. Typically, the polypeptide is substantially pure when it is at least 60%, by weight, free from the proteins and other organic molecules with which it has been associated during synthesis. Preferably, the preparation is at least 75%, more preferably at least 90% and most preferably at least 99%, by weight, of O-fucosyltransferase. A substantially pure O-fucosyltransferase may be obtained by extraction from a natural source (e.g. CHO cell, human heart, liver, muscle, pancreas tissue or tissue derived cell line), by expression of a recombinant nucleic acid encoding an O-fucosyltransferase polypeptide, or chemically by synthesizing the protein. Purity can be measured by any appropriate method, e.g., column chromatography, polyacrylamide gel electrophoresis, or HPLC analysis.

The phrase "substantially identical" with respect to a polypeptide sequence shall be construed as a polypeptide exhibiting at least 70%, preferably 80%, more preferably 90%, and most preferably 95% sequence identity to the reference polypeptide sequence. The term with respect to a nucleic acid sequence shall be construed as a sequence of nucleotides exhibiting at least 85%, preferably 90%, more preferably 95%, and most preferably 97% sequence identity to the reference nucleic acid sequence. For polypeptides, the length of the comparison sequences will generally be at least 25 amino acids. For nucleic acids, the length will generally be at least 75 nucleotides.

The term "identity" or "homology" is construed to mean the percentage of amino acid residues in the candidate sequence that are identical with the residue of a corresponding sequence to which it is compared, after aligning the sequences and introducing gaps, if necessary to achieve the maximum percent homology for the entire sequence, and not considering any conservative substitutions as part of the sequence identity. Neither N- or C-terminal extensions nor insertions shall be construed as reducing identity or homology. Methods and computer programs for the alignment are well known in the art.

Sequence identity may be measured using sequence analysis software (e.g. Sequence Analysis Software Package, Genetics Computer Group, University of Wisconsin Biotechnology Center, 1710 University Ave., Madison, WI 53705). This software matches similar sequences by assigning degrees of homology to various substitutions, deletions, and other modifications.

The phrase "EGF domain" or "Epidermal Growth Factor domain" shall mean a section, repeating region, motif or structural unit of a secreted polypeptide which is characterized by the presence of six (6) conserved cysteine residues that are expected to form at least three (3) intrachain disulfide bonds in a 1-3, 2-4, and 5-6 pattern.

The phrase “functional fragment or analog” of a native polypeptide is a compound having qualitative biological activity in common with a native polypeptide. Thus, a functional fragment or analog of an O-fucosyltransferase is a compound that has a qualitative biological activity in common with O-fucosyltransferase, i.e. can transfer an activated O-fucose moiety to an amino acid or growing carbohydrate chain. “Functional fragments” include, but are not limited to, peptide fragments of the native polypeptide from any animal species (including humans), and derivatives of native (human and non-human) polypeptides and their fragments, provided that they are able to effect a similar function as the full-length polypeptide. The term “analog” means an amino acid sequence and its glycosylation variants which ^{also} share functionality similar to the full-length active O-fucosyltransferase molecule.

The terms “amino acid” and “amino acids” refer to all naturally occurring L- α -amino acids. The amino acids are identified by either a single-letter or three-letter designations:

Asp	D	aspartic acid	Ile	I	isoleucine
Thr	T	threonine	Leu	L	leucine
Ser	S	serine	Tyr	Y	tyrosine
Glu	E	glutamic acid	Phe	F	phenylalanine
Pro	P	proline	His	H	histidine
Gly	G	glycine	Lys	K	lysine
Ala	A	alanine	Arg	R	arginine
Cys	C	cysteine	Trp	W	tryptophan
Val	V	valine	Gln	Q	glutamine
Met	M	methionine	Asn	N	asparagine
Xaa	X	unknown residue			

The above amino acids can be classified according to the chemical composition and properties of their side chains. They are broadly classified into two groups, charged and uncharged. Each of these groups is divided into subgroups to classify the amino acids more accurately:

1. Charged:
 - acidic residues: aspartic acid, glutamic acid
 - basic residues: lysine, arginine, histidine
2. Uncharged:
 - hydrophilic residues: serine, threonine, asparagine, glutamine

aliphatic residues: glycine, alanine, valine, leucine
non-polar residues: cysteine, methionine, proline
aromatic residues: phenylalanine, tyrosine, tryptophan

The term "amino acid variant" refers to molecules with some differences in their amino acid sequences as compared to a native amino acid sequence.

Substitutional variants are those that have at least one amino acid residue in a native sequence removed and a different amino acid inserted in its place at the same position. The substitutions may be single, where only one amino acid in the molecule has been substituted, or they may be multiple, where two or more amino acids have been substituted in the same molecule.

Insertional variants are those with one or more amino acids inserted immediately adjacent to an amino acid at a particular position in a native sequence. Immediately adjacent to an amino acid means connected to either the α -carboxyl or α -amino functional group of the amino acid.

Deletional variants are those with one or more amino acids in the native amino acid sequence removed. Ordinarily, deletional variants will have one or two amino acids deleted in a particular region of the molecule.

The term "glycosylation variant" is used to refer to a glycoprotein having a glycosylation profile different from that of a native counterpart or to glycosylated variants of a polypeptide unglycosylated in its native form(s). Glycosylation of polypeptides is typically either N-linked or O-linked. N-linked refers to the attachment of the carbohydrate moiety to the side-chain of an asparagine residue. The tripeptide sequences, asparagine-X-serine and asparagine-X-threonine, wherein X is any amino acid except proline, are recognition sequences for enzymatic attachment of the carbohydrate moiety to the asparagine side chain. O-linked glycosylation refers to the attachment of one of the sugars N-acetylgalactosamine, galactose, xylose or fucose to a hydroxyamino acid, most commonly serine or threonine, although 5-hydroxyproline or 5-hydroxylysine may also be involved in O-linked glycosylation.

The term "cell", "cell line" and "cell culture" are used interchangeably, and all such designations include progeny. It is also understood that all progeny may not be precisely identical in DNA content, due to deliberate or inadvertent mutations. Mutant progeny that have the same function or biological property, as screened for in the originally transformed cell, are included.

The "host cells" used in the present invention generally are prokaryotic or eukaryotic hosts. Such host cells are, for example, disclosed in U.S. Patent No. 5,108,901, issued 28 April 1992 and in copending application Serial No. 08/446,915 filed 22 May 1995 and its parent applications. Suitable prokaryotes include gram negative or gram positive organisms, for example *E. coli* or bacilli. A preferred cloning host is *E. coli* 294 (ATCC 31,446) although other gram negative or gram positive prokaryotes such as *E. coli* B, *E. coli* x 1776 (ATCC 31,537), *E. coli* W3110 (ATCC 27,325), *Pseudomonas* species, or *Serratia Marcesans* are suitable. In addition to prokaryotes, eukaryotic microbes such as filamentous fungi and yeasts are suitable hosts for appropriate vectors of the invention. *Saccharomyces cerevisiae*, or common baker's yeast, is one of the most commonly used among lower eukaryotic host microorganisms. However, a number of other genera, species and strains are commonly available and useful herein, such as those disclosed in the above-cited patent and patent applications. A preferred yeast strain for the present invention is *Saccharomyces cerevisiae* HF7c (CLONTECH).

Suitable host cells may also derive from multicellular organisms. Such host cells are capable of complex processing and glycosylation activities. In principle, any higher eukaryotic cell culture is workable, whether from vertebrate or invertebrate culture, although cells from mammals such as humans are preferred. Examples of invertebrate cells include plant and insect cells, eg, Luckow et al., *Bio/Technology* 6, 47-55 (1988); Miller et al., *Genetic Engineering*, Setlow et al., eds., vol. 8, pp. 277-279 (Plenum publishing 1986); and Maseda et al., *Nature* 315, 592-594 (1985). Interest had been greatest in vertebrate cells, and propagation of vertebrate cells in culture (tissue culture) is per se known. See *Tissue Culture*, Academic Press, Kruse and Patterson, eds. (1973). Examples of useful mammalian host cell lines are monkey kidney CV1 line transformed by SV40 (COS-7, ATCC CRL 1651); human embryonic kidney cell line (293 or 293 cells subcloned for growth in suspension cultures, Graham et al., *H. Gen. Virol.*, 36, 59 (1977); baby hamster kidney cells 9BHK, (ATCC CCL 10); Chinese hamster ovary cells/-DHFR (CHO, Urlaub and Chasin, *Proc. Natl. Acad. Sci. USA*, 77, 4216 (1980); mouse sertoli cells (TM4, Mather, *Giol. Reprod.* 23, 243-251 (1980); monkey kidney cells (CV1 ATCC CCL 70); African green monkey kidney cells (VERO-76, ATCC CRL-1587); human cervical carcinoma cells (HELA, ATCC CCL 2); canine kidney cells (MDCK, ATCC CCL 34); buffalo rat liver cells (Hep G2, HB 8065); mouse mammary tumor (MMT 060562, ATCC CCL51); TRI cells (Mather et al., *Annual N.Y. Acad. Sci.* 383, 44068 (1982); MRC 5 cells; FS4 cells; and a human hepatoma cell line (Hep G2). Preferred host cells are human embryonic kidney 293 and Chinese hamster ovary cells. Particularly preferred for the present invention is the insect cell line sf9 as well as other host suitable for baculovirus expression. Ausubel, Ch. 16.9 - 16.11.

“Transformation” means introducing DNA into an organism so that the DNA is replicable, either as an extrachromosomal element or by chromosomal integration.

“Operably linked” means that a gene and a regulatory sequence(s) are connected in such a way as to permit gene expression when the appropriate molecules (eg, transcriptional activator proteins) are bound to the regulatory sequence(s).

“Transfection” refers to the taking up of an expression vector by a host cell whether or not any coding sequences are in fact expressed.

The terms “transfected host cell” and “transformed” refer to the introduction of DNA into a cell. The cell is termed a “host cell” and it may be either prokaryotic or eukaryotic. Typical prokaryotic host cells include various strains of *E. Coli*. Typical eukaryotic host cells are mammalian, such as Chinese hamster ovary or cells of human origin. The introduced DNA sequence may be from the same species as the host cell or a different species from the host cell, or it may be a hybrid DNA sequence, containing some foreign and some homologous DNA.

The terms “replicable expression vector” and “expression vector” refer to a piece of DNA, usually double-stranded, which may have inserted into it a piece of foreign DNA. Foreign DNA is defined as heterologous DNA, which is DNA not naturally found in the host cell. The vector is used to transport the foreign or heterologous DNA into a suitable host cell. Once in the host cell, the vector can replicate independently of the host chromosomal DNA, and several copies of the vector and its inserted (foreign) DNA may be generated.

The term “vector” means a DNA construct containing a DNA sequence which is operably linked to a suitable control sequence capable of effecting the expression of the DNA in a suitable host. Such control sequences include a promoter to effect transcription, an optional operator sequence to control such transcription, a sequence encoding suitable mRNA ribosome binding sites, and sequences which control the termination of transcription and translation. The vector may be a plasmid, a phage particle, or simply a potential genomic insert. Once transformed into a suitable host, the vector may replicate and function independently of the host genome, or may in some instances, integrate into the genome itself. In the present specification, “plasmid” and “vector” are sometimes used interchangeably, as the plasmid is the most commonly used form of vector at present. However, the invention is intended to include such other forms of vectors which serve equivalent functions and which are, or become, known in the art. Preferred expression vectors for

mammalian cell culture expression are based on pRK5 (EP 307,247, Rothe et al., Cell, supra), pSV16B (WO 91/08291) and pVL1392 (Pharmingen).

The term "antibody" is used in the broadest sense and specifically covers single monoclonal antibodies (including agonist and antagonist antibodies), antibody compositions with polypeptopic specificity, as well as antibody fragments (e.g., Fab, F(ab')₂, and Fv) so long as they exhibit the desired biological activity. Antibodies (Abs) and immunoglobulins (Igs) are glycoproteins having the same structural characteristics. While antibodies exhibit binding specificity to a specific antigen, immunoglobulins include both antibodies and other antibody-like molecules which lack antigen specificity. Polypeptides of the latter kind are, for example, produced at low levels by the lymph system and at increased levels by myelomas.

Native antibodies and immunoglobulins are usually heterotetrameric glycoproteins of about 150,000 daltons, composed of two identical light (L) chains and two identical heavy (H) chains. Each light chain is linked to a heavy chain by one covalent disulfide bond, while the number of disulfide linkages varies between the heavy chains of different immunoglobulin isotypes. Each heavy and light chain also has regularly spaced intrachain disulfide bridges. Each heavy chain has at one end a variable domain (V_H) followed by a number of constant domains. Each light chain has a variable domain at one end (V_L) and a constant domain at its other end. The constant domain of the light chain is aligned with the first constant domain of the heavy chain, and the light chain variable domain is aligned with the variable domain of the heavy chain. Particular amino acid residues are believed to form an interface between the light and heavy chain variable domains (Clothis et al., *J. Mol. Biol.* 186, 651-663 (1985); Novotny and Haber, *Proc. Natl. Acad. Sci. USA*, 82, 4592-4596 (1985).

The term "variable" refers to the fact that certain portions of the variable domains differ extensively in sequence among antibodies and are used in the binding and specificity of each particular antibody for its particular antigen. However, the variability is not evenly distributed through the variable domains of antibodies. It is concentrated in three segments called complementarity determining regions (CDRs) or hypervariable regions both in the light chain and the heavy chain variable domains. The more highly conserved portions of variable domains are called the framework (FR). The variable domains of native heavy and light chains each comprise four FR regions, largely adopting a β -sheet configuration, connected by three CDRs, which form loops connecting, and in some cases forming part of, the β -sheet structure. The CDRs in each chain are held together in close proximity by the FR regions and, with the CDRs from the other chain, contribute to the formation of the antigen binding site of antibodies (see Kabat, E.A., Sequences of Proteins of Immunological Interest, National Institute of Health, Bethesda, MD 1991). The constant domains are not involved directly in binding an antibody to an antigen, but exhibit various effector functions, such as

participation of the antibody in antibody-dependent cellular toxicity.

Papain digestion of antibodies produces two identical antigen binding fragments, called Fab fragment, each with a single antigen binding site, and a residual "Fc" fragment, whose name reflects its ability to crystallize readily. Pepsin treatment yields an $F(ab')_2$ fragment that has two antigen combining sites and is still capable of cross-linking antigen.

"Fv" is the minimum antibody fragment which contains a complete antigen recognition and binding site. This region consists of a dimer of one heavy and one light chain variable domain in a tight, non-covalent association. It is in this configuration that the three CDRs of each variable domain interact to define an antigen binding site on the surface of the V_H - V_L dimer. Collectively, the six CDRs confer antigen binding specificity to the antibody. However, even a single variable domain (or half of an Fv comprising only three CDRs specific for an antigen) has the ability to recognize and bind antigen, although at a lower affinity than the entire binding site.

The Fab fragment also contains the constant domain of the light chain and the first constant domain (CH1) of the heavy chain. Fab' fragments differ from Fab fragments by the addition of a few residues at the carboxyl terminus of the heavy chain CH1 domain including one or more cysteines from the antibody hinge region. Fab'-SH is the designation herein for Fab' in which the cysteine residue(s) of the constant domains bear a free thiol group. $F(ab')_2$ antibody fragments originally were produced as pairs of Fab' fragments which have hinge cysteines between them. Other, chemical couplings of antibody fragments are also known.

The light chains of antibodies (immunoglobulin) from any vertebrate species can be assigned to one of two clearly distinct types, called kappa (κ) and lambda (λ), based on the amino acid sequences of their constant domains.

Depending on the amino acid sequences of the constant domain of their heavy chains, immunoglobulins can be assigned to different classes. There are five major classes of immunoglobulins: IgA, IgD, IgE, IgG and IgM, and several of these may be further divided into subclasses (isotypes), e.g. IgG-1, IgG-2, IgG-3, and IgG-4; IgA-1 and IgA-2. The heavy chains constant domains that correspond to the different classes of immunoglobulins are called α , Δ , and μ , respectively. The subunit structures and three-dimensional configurations of different classes of immunoglobulins are well known.

The term "monoclonal antibody" as used herein refers to an antibody obtained from a population of

substantially homogeneous antibodies, i.e., the individual antibodies comprising the population are identical except for possible naturally occurring mutations that may be present in minor amounts. Monoclonal antibodies are highly specific, being directed against a single antigenic site. Furthermore, in contrast to conventional (polyclonal) antibody preparations which typically include different antibodies directed against different determinant (epitopes), each monoclonal antibody is directed against a single determinant on the antigen. In addition to their specificity, the monoclonal antibodies are advantageous in that they are synthesized by the hybridoma culture, uncontaminated by other immunoglobulins. The modifier "monoclonal" indicates the character of the antibody as being obtained from a substantially homogeneous population of antibodies, and is not to be construed as requiring production of the antibody by any particular method. For example, the monoclonal antibodies to be used in accordance with the present invention may be made by the hybridoma method first described by Kohler and Milstein, *Nature* 256, 495 (1975), or may be made by recombinant DNA methods (see eg, U.S.P. 4,816,567).

The monoclonal antibodies herein specifically include "chimeric" antibodies (immunoglobulins) in which a portion of the heavy and/or light chain is identical with or homologous to corresponding sequences in antibodies derived from a particular species or belonging to a particular antibody class or subclass, while the remainder of the chain(s) is identical with or homologous to corresponding sequences in antibodies derived from another species or belonging to another antibody class or subclass, as well as fragments of such antibodies, so long as they exhibit the desired biological activity (USP 4,816,567); Morrison et al, *Proc. Natl. Acad. Sci. USA*, 81, 6851-6855 (1984).

"Humanized" forms of non-human (eg. murine) antibodies are chimeric immunoglobulins, immunoglobulin chains or fragments thereof (such as Fv, Fab, Fab', F(ab')₂ or other antigen-binding subsequences of antibodies) which contain minimal sequence derived from non-human immunoglobulin. For the most part, humanized antibodies are human immunoglobulins (recipient antibody) in which residues from a complementary determining region (CDR) of the recipient are replaced by residues from a CDR of a non-human species (donor antibody) such as mouse, rat or rabbit having the desired specificity, affinity and capacity. In some instances, Fv framework residues of the human immunoglobulin are replaced by corresponding non-human residues. Furthermore, humanized antibody may comprise residues which are found neither in the recipient antibody nor in the imported CDR or framework sequences. These modifications are made to further refine and optimize antibody performance. In general, the humanized antibody will comprise substantially all of at least one, and typically two, variable domains, in which all or substantially all of the CDR regions correspond to those of a non-human immunoglobulin and all or substantially all of the FR regions are those of a human immunoglobulin consensus sequence. The humanized antibody optimally also will comprise

at least a portion of an immunoglobulin constant region (Fc), typically that of a human immunoglobulin. For further details see: Jones et al, *Nature* 321, 522-525 (1986); Reichmann et al., *Nature* 332, 323-329 (1988) and Presta, *Curr. Op. Struct. Biol.* 2, 593-596 (1992).

I. Identification and purification of O-fucosyltransferase:

The native O-fucosyltransferase may, for example, be identified and purified from certain tissues which possess O-fucosyltransferase mRNA and which express it at a detectable level. Rat O-fucosyltransferase, for example, can be obtained from rat liver mRNA (see Sadler et al., *Methods Enzymol.* 83, 458-514 (1982) for procedure). Human O-fucosyltransferase, for example, can be prepared, according to the invention from heart, muscle, kidney and pancreas (See Fig. 10). Additionally, native O-fucosyltransferases can be identified and purified from tissues expressing their mRNAs based upon the presence of O-fucose in expressed proteins from that tissue source.

Cell lysate is prepared by any technique commonly employed in the art. For example, sonication in imidazole buffer aqueous NaCl, followed by centrifugation. The supernatant may then be applied to a series of affinity columns, depending upon the level of purity desired. Initially, we have found that a column of anion exchange followed by a nucleotide binding resin is effective. While any anion exchange resin commonly used in the art is suitable, DE-52 (Whatman) is preferred. Suitable nucleotide binding resins are readily apparent to those of skill in the art, however, preferred for use with the present invention are dye resins, such as Cibacron Blue 3GA. Particularly preferred is Affi-Gel Blue (BioRad). While some O-fucosyltransferase activity will be obtained after these initial purification steps, in order to obtain substantially higher activity, additional chromatography steps wherein affinity columns should be sequentially applied wherein acceptor substrate and donor substrate analogs to O-fucosyltransferase have been associated with an affinity resin. The donor substrate analog can be any which are commonly used in the purification of fucosyltransferases. For example, GDP-hexanolamine associated with Sepharose 4B or any other suitable agarose resin. Beyer et al., *J. Biol. Chem.* 255 (11), 5364-5372 (1980).

The acceptor ligand is prepared by first identifying a polypeptide domain containing an O-glycosylated fucose and then applying commonly employed cloning techniques to amplify, then purifying the expressed product. Particular techniques which can be used for recombinant expression are similar to those explained for the expression of O-fucosyltransferase, *infra*. A particularly useful ligand may be created from the first EGF domain of human factor VII. We have found that when a polyhistidine tag, which is typically located between the signal peptide and the expressed ligand, is instead placed at the C-terminus, the binding between the ligand and the affinity resin is enhanced.

The preferable affinity resins for use with the acceptor substrate ligand are metal chelating resins or IMAC (immobilized metal affinity chromatography) associated with agarose. The use of metal chelating resins permits attachment of the EGF ligand to the resin in a defined orientation, according to the position of polyhistidine sequence. As mentioned previously, we have found that ligand-resin binding was enhanced when the polyhistidine tag was inserted at the C-terminus, rather than the N-terminus of the cDNA insert. It is possible to elute the protein with the ligand together under very mild conditions, such as imidazole or EDTA. The coupling of the recombinant EGF to the metal affinity resin agarose is very simple and fast, and is preferably carried out by mixing the resin and ligand in Tris buffer. It is further possible to use the recombinant EGF without the initial purification on a nickel column. Examples of suitable metal affinity resins are IMAC resins such as Ni^{2+} -NTA (NitroTriaceticAcid)(Qiagen), and metal ligand resins associated with iminodiacetic acid (Pharmacia).

II. Recombinant production of O-fucosyltransferase

Preferably, the O-fucosyltransferase polypeptides of the present invention are prepared by standard recombinant methods by culturing cells transfected to express O-fucosyltransferase nucleic acid. A typical standard method is by transforming the cells with an expression vector and recovering the polypeptide from the cells. However, it is envisioned that the O-fucosyltransferase polypeptides may be produced by homologous recombination, or by recombinant production methods utilizing control elements introduced into cells already containing DNA encoding an O-fucosyltransferase. For example, a powerful promoter/enhancer element, a suppressor, or an exogenous transcription modulatory element may be inserted in the genome of the intended host cell in proximity to an orientation sufficient to influence the transcription of DNA encoding the desired O-fucosyltransferase polypeptide. The control element does not encode the O-fucosyltransferase, rather the DNA is indigenous to the host cell genome. Next, cells can be screened for making the polypeptide of this invention, or for increased or decreased levels of expression, as desired. General techniques of recombinant DNA technology are, for example, disclosed in Sambrook et al., Molecular Cloning: A laboratory Manual, 2d Edition, (Cold Spring Harbor Press, Cold Spring Harbor, New York (1989) and in Ausubel et al, Current Protocols in Molecular Biology, John Wiley and Sons, Inc., USA (1995).

Thus, the invention contemplates a method for producing an O-fucosyltransferase comprising inserting into the genome of a cell containing nucleic acid encoding an O-fucosyltransferase polypeptide, a transcription modulatory element in sufficient proximity and orientation to the nucleic acid molecule to influence transcription thereof, with an optional further step of culturing the cell containing the transcription modulatory

element and the nucleic acid molecule. The invention also contemplates a host cell containing the indigenous O-fucosyltransferase polypeptide nucleotide operably linked to exogenous control sequences recognized by the host cell.

A. Isolation of DNA encoding the O-fucosyltransferases

For the purposes of the present invention, DNA encoding an O-fucosyltransferase polypeptide can be obtained from cDNA libraries prepared from tissue believed to contain an O-fucose glycosylated polypeptide encoding mRNA and to express it at a detectable level. For example, a cDNA library can be constructed by obtaining polyadenylated mRNA from a cell line known to express O-fucose glycosylated polypeptides bearing an EGF domain, and using the mRNA as a template to synthesize double stranded cDNA. Human and non-human cell lines suitable for this purpose have been listed above under the description for "host cells."

Libraries, either cDNA or genomic, are screened with probes designed to identify the gene of interest or the protein encoded by it. For cDNA expression libraries, suitable probes include monoclonal and polyclonal antibodies that recognize and specifically bind to O-fucosyltransferase enzymes. For cDNA libraries, suitable probes include carefully selected oligonucleotide probes (usually of about 20-80 bases in length) that encode known or suspected portions of O-fucosyltransferase polypeptides from the same or different species, and/or complementary or homologous cDNAs or fragments thereof that encode the same or a similar gene. Appropriate probes for screening genomic DNA libraries include, without limitation, oligonucleotides, cDNAs, or fragments thereof that encode the same or a similar gene, and/or homologous genomic DNAs or fragments thereof. Screening the cDNA or genomic library with the selected probe may be conducted using standard procedures as described in Chapters 10-12 of Sambrook et al, Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Press, New York (1989); and in Chapter 6 of Ausubel et al, Current Protocols in Molecular Biology, John Wiley and Sons, USA (1995).

A preferred method of practicing the invention is to use carefully selected oligonucleotide sequences to screen cDNA libraries from various tissues. The oligonucleotide sequences selected should be sufficient in length and sufficiently unambiguous that false positives are minimized. The actual nucleotide sequence(s) is/are usually designed based on regions of an O-fucosyltransferase which have the least codon redundancy. The oligonucleotides may be degenerate (i.e., a mixture of possible codons for a given amino acid(s)) at one or more positions. The use of degenerate oligonucleotides is of particular importance where a library is screened from a species in which preferential codon usage is not known.

The oligonucleotide must be labeled such that it can be detected upon hybridization to DNA in the library being screened. The preferred method of labeling is to use ATP (eg. $\gamma^{32}\text{P}$) and polynucleotide kinase to radiolabel the 5' end of the oligonucleotide. However, other methods may be used to label the oligonucleotide, including, but not limited to, biotinylation or enzyme labeling.

cDNAs encoding O-fucosyltransferases can also be identified and isolated by other known techniques of recombinant DNA technology, such as by direct expression cloning or by using the polymerase chain reaction (PCR) as described in U.S.P. 4,683,195, issued 28 July 1987, in section 14 of Sambrook et al, supra, or in Chapter 15 or Ausubel et al, supra. This method requires the use of oligonucleotide probes that will hybridize to DNA encoding O-fucosyltransferase.

Once cDNA encoding an O-fucosyltransferase from one species has been isolated, cDNAs from other species can also be obtained by cross-species hybridization. According to this approach, human or other mammalian cDNA or genomic libraries are probed by labeled oligonucleotide sequences selected from known O-fucosyltransferase sequences (such as human heart or CHO) in accord with known criteria, among which is that the sequence should be sufficient in length and sufficiently unambiguous that false positives are minimized. Typically, a ^{32}P -labeled oligonucleotide having about 30 to 50 bases is sufficient, particularly if the oligonucleotide contains one or more codons for methionine or tryptophan. Isolated nucleic acid will be DNA that is identified and separated from contaminant nucleic acid encoding other polypeptides from the source of nucleic acid.

Once the sequence is known, the gene encoding a particular O-fucosyltransferase polypeptide can also be obtained by chemical synthesis, following any known technique. For example, Engles and Uhlmann, *Agnew. Chem. Int. Ed. Engl.* 28, 716 (1989). These methods include triester, phosphite, phosphoramidite and H-phosphorate methods, PCR and other autoprimer methods, and oligonucleotide syntheses on solid supports.

B. Amino Acid sequence variants of a native O-fucosyltransferase protein or fragment

Amino acid sequence variants of native O-fucosyltransferases and functional fragments thereof are prepared by methods known in the art by introducing appropriate nucleotide changes into a native or variant O-fucosyltransferase, or by *in vitro* synthesis of the desired polypeptide. There are two principal variables in the construction of amino acid sequence variants: the location of the mutation site and the nature of the mutation. With the exception of naturally-occurring alleles, which do not require the manipulation of the DNA sequence encoding the O-fucosyltransferase, the amino acid sequence variants of O-fucosyltransferase are preferably

constructed by mutating the DNA, either to arrive at an allele or an amino acid sequence variant that does not occur in nature.

Amino acid alterations can be made at sites that differ in O-fucosyltransferases from various species, or in highly conserved regions, depending on the goal to be achieved. For example, mutations which result in an enzyme with greater affinity for the EGF domain of polypeptides would be useful as inhibitors of natural O-fucosyltransferase. In addition, such variants would also be useful in the diagnosis of pathological conditions associated with the overexpression of O-fucosyltransferase. **Moreover, inhibitors of O-fucosyltransferase would be expected to be useful in the treatment of conditions associated with proteins or factors having their efficacy determined at least in part by the presence of O-linked fucose.**

Sites of mutations will typically be modified in series, eg. by (1) substituting first with conservative choices and then with more radical selections depending upon the results achieved, (2) deleting the target residue or residues, or (3) inserting residues of the same or different class adjacent to the located site, or combinations of options (1)-(3).

One helpful technique is called "alanine scanning" (Cunningham and Wells, *Science* 244, 1081-1085 (1985). Here, a residue or group of target residues is identified and substituted by alanine or polyalanine. Those domains demonstrating functional sensitivity to the alanine substitutions are then refined by introducing further or other substitutes at or for the sites of alanine substitution.

After identifying the desired mutation(s), the gene encoding an O-fucosyltransferase variant can for example, be obtained by chemical synthesis as hereinabove described.

More preferably, DNA encoding an O-fucosyltransferase amino acid variant sequence is prepared by site-directed mutagenesis of DNA that encodes an earlier prepared variant or a nonvariant version of O-fucosyltransferase. Site-directed (site-specific) mutagenesis allows the production of O-fucosyltransferase variants through the use of specific oligonucleotide sequences that encode the DNA sequence of the desired mutation, as well as a sufficient number of adjacent nucleotides, to provide a primer sequence of sufficient size and sequence complexity to form a stable duplex on both sides of the deletion junction being traversed. Typically, a primer of about 20 to 25 nucleotides in length is preferred, with about 5 to 10 residues on both sides of the junction of the sequence being altered. In general, the techniques of site-specific mutagenesis are well known in the art, as exemplified by publications such as, Edelman et al, *DNA* 2, 183 (1983). As will be appreciated, the site-specific mutagenesis technique typically employs a phage vector that exists in both a

single-stranded and double-stranded form. Typical vectors useful in site-directed mutagenesis include vectors such as the M13 phage, for example, as disclosed by Messing et al, *Third Cleveland Symposium on Macromolecules and Recombinant DNA*, A. Walton, ed., Elsevier, Amsterdam (1981). This and other phage vectors are commercially available and their use is well known to those of ordinary skill in the art. A versatile and efficient procedure for the construction of oligodeoxyribonucleotide directed site-specific mutations in DNA fragments using M13-derived vectors was published by Zoller, MJ and Smith, M, *Nucleic Acids Res.* 10, 6487-6500 (1982). Also, plasmid vectors that contain a single-stranded phage origin of replication, Veira et al., *Meth. Enzymol.* 153, 3 (1987) may be employed to obtain single-stranded DNA. Alternatively, nucleotide substitutions are introduced by synthesizing the appropriate DNA fragment in vitro, and amplifying it by PCR procedures known in the art.

In general, site-specific mutagenesis herewith is performed by first obtaining a single-stranded vector that includes within its sequence a DNA sequence that encodes the relevant protein. An oligonucleotide primer bearing the desired mutated sequence is prepared, generally synthetically, for example, by the method of Crea et al, *Proc. Natl. Acad. Sci. USA* 75, 5765 (1978). This primer is then annealed with the single-stranded protein sequence-containing vector, and subjected to DNA-polymerizing enzymes such as, E. Coli polymerase I Klenow fragment, to complete the synthesis of the mutation -bearing strand. Thus, a heteroduplex is formed wherein one strand encodes the original non-mutated sequence and the second strand bears the desired mutation. This heteroduplex vector is then used to transform appropriate host cells such as JP101 cells, and clones are selected that include recombinant vectors bearing the mutated sequence arrangement. Thereafter, the mutated region may be removed and placed in an appropriate expression vector for protein production.

The PCR technique may also be used in creating amino acid sequence variants of an O-fucosyltransferase. When small amounts of template DNA are used as starting material in a PCR, primers that differ slightly in sequence from the corresponding region in a template DNA can be used to generate relatively large quantities of a specific DNA fragment that differs from the template sequence only at the positions where the primers differ from the template. For introduction of a mutation into a plasmid DNA, one of the primers is designed to overlap the position of the mutation and to contain the mutation; the sequence of the other primer must be identical to a stretch of sequence of the opposite strand of the plasmid, but this sequence can be located anywhere along the plasmid DNA. It is preferred, however, that the sequence of the second primer is located within 200 nucleotides from that of the first, such that in the end the entire amplified region of DNA bounded by the primers can be easily sequenced. PCR amplification using a primer pair like the one just described results in a population of DNA fragments that differ at the position of the mutation specified by the primer, and possibly at other positions, as template copying is somewhat error-prone.

If the ratio of template to product material is extremely low, the vast majority of product DNA fragments incorporate the desired mutations(s). This product material is used to replace the corresponding region in the plasmid that served as PCR template using standard DNA technology. Mutations at separate positions can be introduced simultaneously by either using a mutant second primer or performing a second PCR with different mutant primers and ligating the two resulting PCR fragments simultaneously to the vector fragment in a three (or more) part ligation.

In a specific example of PCR mutagenesis, template plasmid DNA (1 µg) is linearized by digestion with a restriction endonuclease that has a unique recognition site in the plasmid DNA outside of the region to be amplified. Of this material, 100 ng is added to a PCR mixture containing PCR buffer, which contains the four deoxynucleotide triphosphate and is included in the GeneAmp® kits (obtained from Perkin-Elmer Cetus, Norwalk, CT and Emeryville, CA) and 25 pmole of each oligonucleotide primer, to a final volume of 50 µl. The reaction mixture is overlaid with 35 µl mineral oil. The reaction is denatured for 5 minutes at 100°C, placed briefly on ice, and then 1 µl *Thermus aquaticus* (Taq) DNA polymerase (5 units/l) purchased from Perkin-Elmer Cetus, Norwalk, CT and Emeryville, CA) is added below the mineral oil layer. The reaction mixture is then inserted into a DNA Thermal Cycler (also purchased from Cetus) and programmed as follows:

2 min. 55°C
30 sec. 72°C, then 19 cycles of the following:
30 sec. 94°C
30 sec. 72°C.

At the end of the program, the reaction vial is removed from the thermal cycler and the aqueous phase transferred to a new vial, extracted with phenol/chloroform (50:50 vol), and ethanol precipitated, and the DNA is recovered by standard procedures. This material subsequently subjected to appropriate treatments for insertion into a vector.

Another method for preparing variants, cassette mutagenesis, is based on the technique described by Wells et al, *Gene* 34, 315 (1985). The starting material is the plasmid (or vector) comprising the O-fucosyltransferase DNA to be mutated. The codon(s) within the O-fucosyltransferase to be mutated are identified. There must be a unique restriction endonuclease site on each side of the identified mutation site(s). If no such restriction sites exist, they may be generated using the above-described oligonucleotide-mediated mutagenesis method to introduce them at appropriate locations in the O-fucosyltransferase DNA. After the restriction sites have been introduced into the plasmid, the plasmid is cut at these sites to linearize it. A double-

stranded oligonucleotide encoding sequence of the DNA between the restriction site but containing the desired mutation(s) is synthesized using standard procedures. The two strands are synthesized separately and then hybridized together using standard techniques. This double-stranded oligonucleotide is referred to as the cassette. This cassette is designed to have 3' and 5' ends that are compatible with the ends of the linearized plasmid, such that it can be directly ligated to the plasmid. This plasmid now contains mutated O-fucosyltransferase DNA sequence.

Further details of the foregoing and similar mutagenesis techniques are found in general Molecular Biology textbooks, for example, Sambrook et al, supra, and Current protocols in Molecular Biology, Ausubel, et al., supra.

Substitutions of particular amino acid residues based on common side chain properties is also anticipated within the scope of this invention. Naturally-occurring amino acids are divided into groups based on common side chain properties:

- (1) hydrophobic: norleucine, met, ala, val, leu, ile;
- (2) neutral hydrophobic: cys, ser, thr;
- (3) acidic: asp, glu;
- (4) basic: asn, gln, his, lys, arg;
- (5) residues that influence chain orientation: gly, pro; and
- (6) aromatic: trp, tyr, phe

Conservative substitutions involve exchanging a member within one group for another member within the same group, whereas non-conservative substitutions will entail exchanging a member of one of these classes for another. Variants obtained by non-conservative substitutions are expected to result in significant changes in the biological properties/function of the obtained variant, and may result in a non-functional O-fucosyltransferase. Amino acid positions that are conserved among various species are generally substituted in a relatively conservative manner if the goal is to retain biological function.

Amino acid sequence deletions range from about 1 to 30 residues, more preferably about 1 to 10 residues, and typically are contiguous. Deletions, may be introduced into regions not directly involved in the catalytic domain.

Amino acid insertions include amino- and/or carboxyl-terminal fusions ranging in length from one residue to polypeptides containing a hundred or more residues, as well as intrasequence insertions of single or multiple amino acid residues. Intrasequence insertions (i.e., insertions within the O-fucosyltransferase amino

acid sequence) may range generally from about 1 to about 10 residues, more preferably 1 to 5 residues, most preferably 1 to 3 residues. Examples of terminal insertions include the O-fucosyltransferase polypeptides with an N-terminal methionyl residue, an artifact of its direct expression in bacterial recombinant cell culture, and fusion of a heterologous N-terminal signal sequence to the N-terminus of the O-fucosyltransferase molecule to facilitate the secretion of the mature O-fucosyltransferase from recombinant host cells. Such signal sequences will generally be obtained from, and thus homologous to the intended host cell species. Suitable sequences include STII or lpp for E. Coli., alpha factor for yeast, and viral signals such as herpes gD for mammalian cells.

Since it is often difficult to predict in advance the characteristics of a variant O-fucosyltransferase, it will be appreciated that some screening will be needed to select the optimum variant.

C. Insertion of DNA into Cloning Vehicle

Once the nucleic acid encoding a native or variant O-fucosyltransferase is available, it is generally ligated into a replicable expression vector for further cloning (amplification of the DNA), or for expression.

Expression and cloning vectors are well known in the art and contain a nucleic acid sequence that enables the vector to replicate in one or more selected host cells. The selection of the appropriate vector will depend on 1) whether it is to be used for DNA amplification or for DNA expression, 2) the size of the DNA to be inserted into the vector, and 3) the host cell to be transformed with the vector. Each vector contains various components depending on its function (amplification of DNA or expression of DNA) and the host cell for which it is compatible. The vector components generally include, but are not limited to, one or more of the following: a signal sequence, an origin or replication, one or more marker genes, an enhancer element, a promoter, and a transcription termination sequence.

(1) Signal sequence Component

In general, the signal sequence may be a component of the vector, or it may be a part of the O-fucosyltransferase molecule that is inserted into the vector. If the signal sequence is heterologous, it should be selected such that it is recognized and processed (i.e., cleaved by a signal peptidase) by the host cell.

Since O-fucosyltransferase is likely a membrane-bound protein, it is likely to have a native signal sequence. This native signal sequence can be used or another may be chosen. Heterologous signal sequences suitable for prokaryotic host cells are prokaryotic signal sequences, such as the alkaline phosphatase, penicillinase, lpp, or heat-stable enterotoxin II leaders. For yeast secretion, the yeast invertase, alpha factor, or

acid phosphatase leaders may be used. In mammalian cell expression, mammalian signal sequences are suitable.

(2) Origin of Replication Component

Both expression and cloning vectors contain a nucleic acid that enables the vector to replicate in one or more selected host cells. Generally, in cloning vectors this sequence is one that enables the vector to replicate independently of the host chromosomes, and includes origins or replication or autonomously replicating sequences. Such sequences are well known for a variety of bacteria, yeast and viruses. The origin of replication from the well-known plasmid pBR322 is suitable for most gram negative bacteria, the 2 μ plasmid origin for yeast and various viral origins (SV40, polyoma, adenovirus, VSV, BPV) are useful for cloning vectors in mammalian cells. Origins of replication are not needed for mammalian expression vectors (the SV40 origin may typically be used only because it contains the early promoter). Most expression vectors are "shuttle" vectors, i.e. they are capable of replication in at least one class of organisms but can be transfected into another organism for expression. For example, a vector is cloned in *E. coli* and then the same vector is transformed into yeast or mammalian cells for expression even though it is not capable of replicating independently of the host cell chromosome.

DNA is also cloned by insertion into the host genome. This is readily accomplished using *Bacillus* species as hosts, for example, by including in the vector a DNA sequence that is complementary to a sequence found in *Bacillus* genomic DNA. Transfection of *Bacillus* with this vector results in homologous recombination with the genome and insertion of the DNA encoding the desired heterologous polypeptide. However, the recovery of genomic DNA is more complex than that of an exogenously replicated vector because restriction enzyme digestion is required to excise the encoded polypeptide molecule.

(3) Selection Gene Component

Expression and cloning vectors should contain a selection gene, also termed a selectable marker. This is a gene that encodes a protein necessary for the survival or growth of host cell transformed with the vector. The presence of this gene ensures that any host cell which deletes the vector will not obtain an advantage in growth or reproduction over transformed hosts. Typical selection genes encode proteins that (a) confer resistance to antibiotics or other toxins, eg, ampicillin, neomycin, methotrexate or tetracycline, (b) complement autotrophic deficiencies, or (c) supply critical nutrients not available from complex media, eg. the gene encoding D-alanine racemase for bacilli.

One example of a selection scheme utilizes a drug to arrest growth of a host cell. Those cells that are successfully transformed with a heterologous gene express a protein conferring drug resistance and thus survive the selection regimen. Examples of such dominant selection use the drugs neomycin, Southern et al., *J. Molec. Appl. Genet.* 1, 327 (1982), mycophenolic acid, Mulligan et al., *Science* 209, 1422 (1980), or hygromycin, Sudgen et al., *Mol. Cel. Biol.* 5, 410-413 (1985). The three examples given above employ bacterial genes under eukaryotic control to convey resistance to the appropriate drug G418 or neomycin (geneticin), xgpt (mycophenolic acid), or hygromycin, respectively.

Other examples of suitable selectable markers for mammalian cells are dihydrofolate reductase (DHFR) or thymidine kinase. Such markers enable the identification of cells which were competent to take up the desired nucleic acid. The mammalian cell transformants are placed under selection pressure which only the transformants are uniquely adapted to survive by virtue of having taken up the marker. Selection pressure is imposed by culturing the transformants under conditions in which the concentration of selection agent in the medium is successively changed, thereby leading to amplification of both the selection gene and the DNA that encodes the desired polypeptide. Amplification is the process by which genes in greater demand for the production of a protein critical for growth are reiterated in tandem within the chromosomes of successive generations of recombinant cells. Increased quantities of the desired polypeptide are synthesized from the amplified DNA.

For example, cells transformed with the DHFR selection gene are first identified by culturing all of the transformants in a culture medium which lacks hypoxanthine, glycine, and thymidine. An appropriate host cell in this case is the Chinese hamster ovary (CHO) cell line deficient in DHFR activity, prepared and propagated as described by Urlaub and Chasin, *Proc. Nat'l. Acad. Sci. USA* 77, 4216 (1980). A particularly useful DHFR is a mutant DHFR that is highly resistant to MTX (EP 117,060). This selection agent can be used with any otherwise suitable host, e.g. ATCC No. CCL61 CHO-K1, notwithstanding the presence of endogenous DHFR. The DNA encoding DHFR and the desired polypeptide, respectively, then is amplified by exposure to an agent (methotrexate, or MTX) that inactivates the DHFR. One ensures that the cell requires more DHFR (and consequently amplifies all exogenous DNA) by selecting only for cells that can grow in successive rounds of ever-greater MTX concentration. Alternatively, hosts co-transformed with genes encoding the desired polypeptide, wild-type DHFR, and another selectable marker such as the neo gene can be identified using a selection agent for the selectable marker such as G418 and then selected and amplified using methotrexate in a wild-type host that contains endogenous DHFR. (See also U.S. Patent No. 4,965,199).

A suitable selection gene for use in yeast is the trp1 gene present in the yeast plasmid YRp7

(Stinchcomb *et al.*, 1979, *Nature* 282:39; Kingsman *et al.*, 1979, *Gene* 7:141; or Tschemper *et al.*, 1980, *Gene* 10:157). The trp1 gene provides a selection marker for a mutant strain of yeast lacking the ability to grow in tryptophan, for example, ATCC No. 44076 or PEP4-1 (Jones, 1977, *Genetics* 85:12). The presence of the trp1 lesion in the yeast host cell genome then provides an effective environment for detecting transformation by growth in the absence of tryptophan. Similarly, Leu2 deficient yeast strains (ATCC 20,622 or 38,626) are complemented by known plasmids bearing the Leu2 gene.

(4) Promoter Component

Expression vectors, unlike cloning vectors, should contain a promoter which is recognized by the host organism and is operably linked to the nucleic acid encoding the desired polypeptide. Promoters are untranslated sequences located upstream from the start codon of a structural gene (generally within about 100 to 1000 bp) that control the transcription and translation of nucleic acid under their control. They typically fall into two classes, inducible and constitutive. Inducible promoters are promoters that initiate increased levels of transcription from DNA under their control in response to some change in culture conditions, e.g. the presence or absence of a nutrient or a change in temperature. At this time a large number of promoters recognized by a variety of potential host cells are well known. These promoters are operably linked to DNA encoding the desired polypeptide by removing them from their gene of origin by restriction enzyme digestion, followed by insertion 5' to the start codon for the polypeptide to be expressed. This is not to say that the genomic promoter for a O-fucosyltransferase polypeptide is not usable. However, heterologous promoters generally will result in greater transcription and higher yields of expressed O-fucosyltransferase as compared to the native O-fucosyltransferase promoters.

Promoters suitable for use with prokaryotic hosts include the β -lactamase and lactose promoter systems (Chang *et al.*, *Nature* 275:615 (1978); and Goeddel *et al.*, *Nature* 281:544 (1979)), alkaline phosphatase, a tryptophan (trp) promoter system (Goeddel, *Nucleic Acids Res.* 8:4057 (1980) and EPO Appln. Publ. No. 36,776) and hybrid promoters such as the tac promoter (H. de Boer *et al.*, *Proc. Nat'l. Acad. Sci. USA* 80:21-25 (1983)). However, other known bacterial promoters are suitable. Their nucleotide sequences have been published, thereby enabling a skilled worker operably to ligate them to DNA encoding O-fucosyltransferase (Siebenlist *et al.*, *Cell* 20:269 (1980)) using linkers or adaptors to supply any required restriction sites. Promoters for use in bacterial systems also will contain a Shine-Dalgarno (S.D.) sequence operably linked to the DNA encoding an O-fucosyltransferase.

Suitable promoting sequences for use with yeast hosts include the promoters for 3-phosphoglycerate kinase (Hitzeman *et al.* *J. Biol. Chem.* 255:2073 (1980)) or other glycolytic enzymes (Hess *et al.*, *J. Adv.*

Enzyme Reg. 7:149 (1978); and Holland, *Biochemistry* 17:4900 (1978)), such as enolase, glyceraldehyde-3-phosphate dehydrogenase, hexokinase, pyruvate decarboxylase, phosphofructokinase, glucose-6-phosphate isomerase, 3-phosphoglycerate mutase, pyruvate kinase, triosephosphate isomerase, phosphoglucose isomerase, and glucokinase.

Other yeast promoters, which are inducible promoters having the additional advantage of transcription controlled by growth conditions, are the promoter regions for alcohol dehydrogenase 2, isocytochrome C, acid phosphatase, degradative enzymes associated with nitrogen metabolism, metallothionein, glyceraldehyde-3-phosphate dehydrogenase, and enzymes responsible for maltose and galactose utilization. Suitable vectors and promoters for use in yeast expression are further described in R. Hitzeman *et al.*, EP 73,657A. Yeast enhancers also are advantageously used with yeast promoters.

Promoter sequences are known for eukaryotes. Virtually all eukaryotic genes have an AT-rich region located approximately 25 to 30 bases upstream from the site where transcription is initiated. Another sequence found 70 to 80 bases upstream from the start of transcription of many genes is a CXCAAT region where X may be any nucleotide. At the 3' end of most eukaryotic genes is an AATAAA sequence that may be the signal for addition of the poly A tail to the 3' end of the coding sequence. All of these sequences are suitably inserted into mammalian expression vectors.

O-fucosyltransferase transcription from vectors in mammalian host cells may be controlled by promoters obtained from the genomes of viruses such as polyoma virus, fowlpox virus (UK 2,211,504 published 5 July 1989), adenovirus (such as Adenovirus 2), bovine papilloma virus, avian sarcoma virus, cytomegalovirus, a retrovirus, hepatitis-B virus and most preferably Simian Virus 40 (SV40), from heterologous mammalian promoters, e.g. the actin promoter or an immunoglobulin promoter, from heat shock promoters, and from the promoter normally associated with the O-fucosyltransferase sequence, provided such promoters are compatible with the host cell systems.

The early and late promoters of the SV40 virus are conveniently obtained as an SV40 restriction fragment which also contains the SV40 viral origin of replication [Fiers *et al.*, *Nature* 273:113 (1978), Mulligan and Berg, *Science* 209, 1422-1427 (1980); Pavlakis *et al.*, *Proc. Natl. Acad. Sci. USA* 78, 7398-7402 (1981)]. The immediate early promoter of the human cytomegalovirus is conveniently obtained as a HindIII E restriction fragment [Greenaway *et al.*, *Gene* 18, 355-360 (1982)]. A system for expressing DNA in mammalian hosts using the bovine papilloma virus as a vector is disclosed in US 4,419,446. A modification of this system is described in US 4,601,978. See also, Gray *et al.*, *Nature* 295, 503-508 (1982) on expressing

cDNA encoding human immune interferon in monkey cells; Reyes *et al.*, *Nature* 297, 598-601 (1982) on expressing human β -interferon cDNA in mouse cells under the control of a thymidine kinase promoter from herpes simplex virus; Canaani and Berg, *Proc. Natl. Acad. Sci. USA* 79, 5166-5170 (1982) on expression of the human interferon β 1 gene in cultured mouse and rabbit cells; and Gorman *et al.*, *Proc. Natl. Acad. Sci., USA* 79, 6777-6781 (1982) on expression of bacterial CAT sequences in CV-1 monkey kidney cells, chicken embryo fibroblasts, Chinese hamster ovary cells, HeLa cells, and mouse HIN-3T3 cells using the Rous sarcoma virus long terminal repeat as a promoter.

(5) Enhancer Element Component

Transcription of a DNA encoding the O-fucosyltransferases of the present invention by higher eukaryotes is often increased by inserting an enhancer sequence into the vector. Enhancers are cis-acting elements of DNA, usually about from 10 to 300 bp, that act on a promoter to increase its transcription. Enhancers are relatively orientation and position independent having been found 5' [Laimins *et al.*, *Proc. Natl. Acad. Sci. USA* 78, 993 (1981)] and 3' [Lasky *et al.*, *Mol. Cel. Biol.* 3, 1108 (1983)] to the transcription unit, within an intron [Banerji *et al.*, *Cell* 33, 729 (1983)] as well as within the coding sequence itself [Osborne *et al.*, *Mol. Cel.. Biol.* 4, 1293 (1984)]. Many enhancer sequences are now known from mammalian genes (globin, elastase, albumin, α -fetoprotein and insulin). Typically, however, one will use an enhancer from a eukaryotic cell virus. Examples include the SV40 enhancer on the late side of the replication origin (bp 100-270), the cytomegalovirus early promoter enhancer, the polyoma enhancer on the late side of the replication origin, and adenovirus enhancers. See also Yaniv, *Nature* 297, 17-18 (1982) on enhancing elements for activation of eukaryotic promoters. The enhancer may be spliced into the vector at a position 5' or 3' to the O-fucosyltransferase DNA, but is preferably located at a site 5' from the promoter.

(6) Transcription Termination Component

Expression vectors used in eukaryotic host cells (yeast, fungi, insect, plant, animal, human, or nucleated cells from other multicellular organisms) will also contain sequences necessary for the termination of transcription and for stabilizing the mRNA. Such sequences are commonly available from the 5' and, occasionally 3' untranslated regions of eukaryotic or viral DNAs or cDNAs. These regions contain nucleotide segments transcribed as polyadenylated fragments in the untranslated portion of the mRNA encoding the O-fucosyltransferase. The 3' untranslated regions also include transcription termination sites.

Construction of suitable vectors containing one or more of the above listed components, the desired coding and control sequences, employs standard ligation techniques. Isolated plasmids or DNA fragments are cleaved, tailored, and religated in the form desired to generate the plasmids required.

For analysis to confirm correct sequences in plasmids constructed, the ligation mixtures are used to transform *E. coli* K12 strain 294 (ATCC 31,446) and successful transformants selected by ampicillin or tetracycline resistance where appropriate. Plasmids from the transformants are prepared, analyzed by restriction endonuclease digestion, and/or sequenced by the method of Messing *et al.*, *Nucleic Acids Res.* 9, 309 (1981) or by the method of Maxam *et al.*, *Methods in Enzymology* 65, 499 (1980).

Particularly useful in the practice of this invention are expression vectors that provide for the transient expression in mammalian cells of DNA encoding an O-fucosyltransferase. In general, transient expression involves the use of an expression vector that is able to replicate efficiently in a host cell, such that the host cell accumulates many copies of the expression vector and, in turn, synthesizes high levels of a desired polypeptide encoded by the expression vector. Transient systems, comprising a suitable expression vector and a host cell, allow for the convenient positive identification of polypeptides encoded by clones DNAs, as well as for the rapid screening of such polypeptides for desired biological or physiological properties. Thus, transient expression systems are particularly useful in the invention for purposes of identifying analogs and variants of an O-fucosyltransferase.

Other methods, vectors, and host cells suitable for adaptation to the synthesis of the O-fucosyltransferase polypeptides in recombinant vertebrate cell culture are described in Getting *et al.*, *Nature* 293, 620-625 (1981); Mantel *et al.*, *Nature* 281, 40-46 (1979); Levinson *et al.*; EP 117,060 and EP 117,058. A particularly useful plasmid for mammalian cell culture expression of the O-fucosyltransferase polypeptides is pRK5 (EP 307,247). Especially preferred are baculovirus expression systems as described in Ausuble, Ch. 16.9 - 16.11, *supra*, in particular, pVL1392. (Pharmingen).

(7) Construction and analysis of vectors

Construction of suitable vectors containing one or more of the above listed components employs standard ligation techniques. Isolated plasmids or DNA fragments are cleaved, tailored, and religated in the form desired to generate the plasmids required.

For analysis to confirm correct sequences in plasmids constructed, the ligation mixtures are used to transform *E. coli* K12 strain 294 (ATCC 31,446) and successful transformants selected by ampicillin or tetracycline resistance where appropriate. Plasmids from the transformants are prepared, analyzed by restriction endonuclease digestion, and/or sequences by the methods of Messing *et al.*, *Nuclei Acids Res.* 9, 309 (1981) or by the method of Maxam *et al.*, *Methods in Enzymology* 65, 499 (1980).

(8) Transient expression vectors

Particularly useful in the practice of this invention are expression vectors that provide for the transient expression in mammalian cells of DNA encoding a O-fucosyltransferase polypeptide. In general, transient expression involves the use of an expression vector that is able to replicate efficiently in a host cell, such that the host cell accumulates many copies of the expression vector and, in turn, synthesizes high level of a desired polypeptide encoded by the expression vector. Sambrook *et al.*, supra, pp. 16.17-16.22. Transient expression systems, comprising a suitable expression vector and a host cell, allow for the convenient positive screening of such polypeptides for desired biological or physiological properties. Thus transient expression systems are particularly useful in the invention for purposes of identifying analogs and variants of native O-fucosyltransferase polypeptides with O-fucosyltransferase enzymatic activity.

(9) Suitable exemplary vertebrate cell vectors

Other methods, vectors, and host cells suitable for adaptation to the synthesis of a O-fucosyltransferase polypeptide (including functional derivatives of native proteins) in recombinant vertebrate cell culture are described in Gething *et al.*, *Nature* 293, 620-625 (1981); Mantei *et al.*, *Nature* 281, 40-46 (1979); Levinson *et al.*, EP 117,060; and EP 117,058. A particularly useful plasmid for mammalian cell culture expression of an O-fucosyltransferase polypeptide is pRK5 (EP 307,247), pSV16B (PCT Publication No. WO 91/08291). Particularly preferred is insect vector pVL1392 (Pharming), Ausubel, Ch. 16.9 - 16.11, *supra*.

III. Selection and Transformation of Host Cells

Suitable host cells for cloning or expressing the vectors herein are the prokaryote, yeast or higher eukaryote cells described above. Suitable prokaryotes include gram negative or gram positive organisms, for example *E. coli* or bacilli. A preferred cloning host is *E. coli* 294 (ATCC 31,446) although other gram negative or gram positive prokaryotes such as *E. coli* B, *E. coli* X1776 (ATCC 31,537), *E. coli* W3110 (ATCC 27,325), *Pseudomonas* species, or *Serratia Marcesans* are suitable.

In addition to prokaryotes, eukaryotic microbes such as filamentous fungi or yeast are suitable hosts for vectors herein. *Saccharomyces cerevisiae*, or common baker's yeast, is the most commonly used among lower eukaryotic host microorganisms. However, a number of other genera, species and strains are commonly available and useful herein, such as *S. pombe* [Beach and Nurse, *Nature* 290, 140 (1981)], *Kluyveromyces lactis* [Louvencourt *et al.*, *J. Bacteriol.* 737 (1983)]; *yarrowia* (EP 402,226); *Pichia pastoris* (EP 183,070), *Trichoderma reesia* (EP 244,234), *Neurospora crassa* [Case *et al.*, *Proc. Natl. Acad. Sci. USA* 76, 5259-5263 (1979)]; and *Aspergillus* hosts such as *A. nidulans* [Ballance *et al.*, *Biochem. Biophys. Res. Commun.* 112, 284-

289 (1983); Tilburn *et al.*, *Gene* **26**, 205-221 (1983); Yelton *et al.*, *Proc. Natl. Acad. Sci. USA* **81**, 1470-1474 (1984)] and *A. niger* [Kelly and Hynes, *EMBO J.* **4**, 475-479 (1985)].

Suitable host cells may also derive from multicellular organisms. Such host cells are capable of complex processing and glycosylation activities. In principle, any higher eukaryotic cell culture is workable, whether from vertebrate or invertebrate culture, although cells from mammals such as humans are preferred. Examples of invertebrate cells include plants and insect cells. Numerous baculoviral strains and variants and corresponding permissive insect host cells from hosts such as *Spodoptera frugiperda* (caterpillar), *Aedes aegypti* (mosquito), *Aedes albopictus* (mosquito), *Drosophila melangaster* (fruitfly), and *Bombyx mori* host cells have been identified. See, e.g. Luckow *et al.*, *Bio/Technology* **6**, 47-55 (1988); Miller *et al.*, in *Genetic Engineering*, Setlow, J.K. *et al.*, eds., Vol. 8 (Plenum Publishing, 1986), pp. 277-279; and Maeda *et al.*, *Nature* **315**, 592-594 (1985). A variety of such viral strains are publicly available, e.g. the L-1 variant of *Autographa californica* NPV, and such viruses may be used as the virus herein according to the present invention, particularly for transfection of *Spodoptera frugiperda* cells.

Plant cell cultures of cotton, corn, potato, soybean, petunia, tomato, and tobacco can be utilized as hosts. Typically, plant cells are transfected by incubation with certain strains of the bacterium *Agrobacterium tumefaciens*, which has been previously manipulated to contain the O-fucosyltransferase DNA. During incubation of the plant cell culture with *A. tumefaciens*, the DNA encoding a O-fucosyltransferase is transferred to the plant cell host such that it is transfected, and will, under appropriate conditions, express the O-fucosyltransferase DNA. In addition, regulatory and signal sequences compatible with plant cells are available, such as the opaline synthase promoter and polyadenylation signal sequences. Depicker *et al.*, *J. Mol. Appl. Gen.* **1**, 561 (1982). In addition, DNA segments isolated from the upstream region of the T-DNA 780 gene are capable of activating or increasing transcription levels of plant-expressible genes in recombinant DNA-containing plant tissue. See EP 321,196 published 21 June 1989.

However, interest has been greatest in vertebrate cells, and propagation of vertebrate cells in culture (tissue culture) is per se well known. See *Tissue Culture*, Academic Press, Kruse and Patterson, editors (1973). Examples of useful mammalian host cell lines are monkey kidney CV1 line transformed by SV40 (COS-7, ATCC CRL 1651); human embryonic kidney cell line [293 or 293 cells subcloned for growth in suspension culture, Graham *et al.*, *J. Gen. Virol.* **36**, 59 (1977)]; baby hamster kidney cells 9BHK, ATCC CCL 10); Chinese hamster ovary cells/-DHFR [CHO, Urlaub and Chasin, *Proc. Natl. Acad. Sci. USA* **77**, 4216 (1980)]; mouse sertoli cells [TM4, Mather, *Biol. Reprod.* **23**, 243-251 (1980)]; monkey kidney cells (CV1 ATCC CCL 70); African green monkey kidney cells (VERO-76, ATCC CRL-1587); human cervical carcinoma cells

(HELA, ATCC CCL 2); canine kidney cells (MDCK, ATCC CCL 34); buffalo rat liver cells (BRL 3A, ATCC CRL 1442); human lung cells (W138, ATCC CCL75); human liver cells (Hep G2, HB 8065); mouse mammary tumor (MMT 060562, ATCC CCL51); TRI cells [Mather *et al.*, *Annals N.Y. Acad. Sci.* 383, 44068 (1982)]; MRC 5 cells; FS4 cells; and a human hepatoma cell line (Hep G2). Preferred host cells are human embryonic kidney 293 and Chinese hamster ovary cells. Most preferred are insect cells capable of baculovirus expression: Sf9 cells, ATCC-CRL 1711, Pharmingen (21300C, Invitrogen (B825-01), or Sf21 cells, Clontech (K1601-E) or Invitrogen. See Ausubel, ch. 16.9 - 16.11, *supra*.

Particularly preferred host cells for the purpose of the present invention are vertebrate cells producing the O-fucosyltransferase polypeptides.

Host cells are transfected and preferably transformed with the above-described expression or cloning vectors and cultured in conventional nutrient media modified as is appropriate for inducing promoters or selecting transformants containing amplified genes.

IV. Culturing Host Cells

Prokaryotes cells used to produced the O-fucosyltransferase polypeptides of this invention are cultured in suitable media as describe generally in Sambrook *et al.*, supra.

Mammalian cells can be cultured in a variety of media. Commercially available media such as Ham's F10 (Sigma), Minimal Essential Medium (MEM, Sigma), RPMI-1640 (Sigma), and Dulbecco's Modified Eagle's Medium (DMEM, Sigma) are suitable for culturing the host cells. In addition, any of the media described in Ham and Wallace, *Meth. Enzymol.* 58, 44 (1979); Barnes and Sato, *Anal. Biochem.* 102, 255 (1980), US 4,767,704; 4,657,866; 4,927,762; or 4,560,655; WO 90/03430; WO 87/00195 or US Pat. Re. 30,985 may be used as culture media for the host cells. Any of these media may be supplemented as necessary with hormones and/or other growth factors (such as insulin, transferrin, or epidermal growth factor), salts (such as sodium chloride, calcium, magnesium, and phosphate), buffers (such as HEPES), nucleosides (such as adenosine and thymidine), antibiotics (such as GentamycinTM drug) trace elements (defined as inorganic compounds usually present at final concentrations in the micromolar range), and glucose or an equivalent energy source. Any other necessary supplements may also be included at appropriate concentrations that would be known to those skilled in the art. The culture conditions, such as temperature, pH and the like, suitably are those previously used with the host cell selected for cloning or expression, as the case may be, and will be apparent to the ordinary artisan.

The host cells referred to in this disclosure encompass cells in *in vitro* cell culture as well as cells that are within a host animal or plant.

It is further envisioned that the O-fucosyltransferase polypeptides of this invention may be produced by homologous recombination, or with recombinant production methods utilizing control elements introduced into cells already containing DNA encoding the particular O-fucosyltransferase.

V. Detecting Gene Amplification/Expression

Gene amplification and/or expression may be measured in a sample directly, for example, by conventional Southern blotting, Northern blotting to quantitate the transcription of mRNA [Thomas, *Proc. Natl. Acad. Sci. USA* 77, 5201-5205 (1980)], dot blotting (DNA analysis), or *in situ* hybridization, using an appropriately labeled probe, based on the sequences provided herein. Various labels may be employed, most commonly radioisotopes, particularly ³²P. However, other techniques may also be employed, such as using biotin-modified nucleotides for introduction into a polynucleotide. The biotin then serves as a site for binding to avidin or antibodies, which may be labeled with a wide variety of labels, such as radionuclides, fluorescers, enzymes, or the like. Alternatively, antibodies may be employed that can recognize specific duplexes, including DNA duplexes, RNA duplexes, and DNA-RNA hybrid duplexes or DNA-protein duplexes. The antibodies in turn may be labeled and the assay may be carried out where the duplex is bound to the surface, so that upon the formation of duplex on the surface, the presence of antibody bound to the duplex can be detected.

Gene expression, alternatively, may be measured by immunological methods, such as immunohistochemical staining of tissue sections and assay of cell culture or body fluids, to quantitate directly the expression of gene product. With immunohistochemical staining techniques, a cell sample is prepared, typically by dehydration and fixation, followed by reaction with labeled antibodies specific for the gene product coupled, where the labels are usually visually detectable, such as enzymatic labels, fluorescent labels, luminescent labels, and the like. A particularly sensitive staining technique suitable for use in the present invention is described by Hse *et al.*, *Am. J. Clin. Pharm.* 75, 734-738 (1980).

Antibodies useful for immunohistochemical staining and/or assay of sample fluids may be either monoclonal or polyclonal, and may be prepared in any animal. Conveniently, the antibodies may be prepared against a native O-fucosyltransferase polypeptide, or against a synthetic polypeptide based on the DNA sequence provided herein as described further hereinbelow.

VI. Covalent Modifications of O-fucosyltransferase Polypeptides

Covalent modifications of O-fucosyltransferase are included within the scope of this invention. Such modifications are traditionally introduced by reacting targeted amino acid residues of the O-fucosyltransferase with an organic derivatizing agent that is capable of reacting with selected sides or terminal residues, or by harnessing mechanisms of post-translational modifications that function in selected recombinant host cells. The resultant covalent derivatives are useful in programs directed at identifying residues important for biological activity, for immunoassays of the fucosyltransferase, or for the preparation of fucosyltransferase antibodies for immunoaffinity purification of the recombinant. For example, complete inactivation of the biological activity of the protein after reaction with ninhydrin would suggest that at least one arginyl or lysyl residue is critical for its activity, whereafter the individual residues which were modified under the conditions selected are identified by isolation of a peptide fragment containing the modified amino acid residue. Such modifications are within the ordinary skill in the art and are performed without undue experimentation.

Cysteiny l residues most commonly are reacted with α -haloacetates (and corresponding amines), such as chloroacetic acid or chloroacetamide, to give carboxymethyl or carboxyamidomethyl derivatives. Cysteiny l residues also are derivatized by reaction with bromotrifluoroacetone, α -bromo- β -(5-imidazolyl)propionic acid, chloroacetyl phosphate, N-alkylmaleimides, 3-nitro-2-pyridyl disulfide, methyl 2-pyridyl disulfide, p-chloromercuribenzoate, 2-chloromercuri-4-nitrophenol, or chloro-7-nitrobenzo-2-oxa-1,3-diazole.

Histidyl residues are derivatized by reaction with diethylpyrocarbonate at pH 5.5-7.0 because this agent is relatively specific for the histidyl side chain. Para-bromophenacyl bromide also is useful; the reaction is preferably performed in 0.1M sodium cacodylate at pH 6.0.

Lysiny l and amino terminal residues are reacted with succinic or other carboxylic acid anhydrides. Derivatization with these agents has the effect of reversing the charge of the lysiny l residues. Other suitable reagents for derivatizing α -amino-containing residues include imidoesters such as methyl picolinimide; pyridoxal phosphate; pyridoxal; chloroborohydride; trinitrobenzenesulfonic acid; O-methylisourea; 2,4-pentanedione; and transaminase-catalyzed reaction with glyoxylate.

Arginy l residues are modified by reaction with one or several conventional reagents, among them phenylglyoxal, 2,3-butanedione, 1,2-cyclohexanedione, and ninhydrin. Derivatization of arginine residues requires that the reaction be performed in alkaline conditions because of the high pK_a of the guanidine functional group. Furthermore, these reagents may react with the groups of lysine as well as the arginine epsilon-amino group.

The specific modification of tyrosyl residues may be made, with particular interest in introducing spectral labels into tyrosyl residues by reaction with aromatic diazonium compounds or tetranitromethane. Most commonly, N-acetylimidazole and tetranitromethane are used to form O-acetyl tyrosyl species and 3-nitro derivatives, respectively. Tyrosyl residues are iodinated using ^{125}I or ^{131}I to prepare labeled proteins for use in radioimmunoassay.

Carboxyl side groups (aspartyl or glutamyl) are selectively modified by reaction with carbodiimides ($\text{R}'\text{-N}=\text{C}=\text{N-R}'$) such as 1-cyclohexyl-3-(2-morpholinyl-4-ethyl) carbodiimide or 1-ethyl-3-(4-azonia-4,4-dimethylpentyl) carbodiimide. Furthermore, aspartyl and glutamyl residues are converted to asparaginyl and glutaminyl residues by reaction with ammonium ions.

Glutaminyl and asparaginyl residues are frequently deamidated to the corresponding glutamyl and aspartyl residues. Alternatively, these residues are deamidated under mildly acidic conditions. Either form of these residues falls within the scope of this invention.

Other modifications include hydroxylation of proline and lysine, phosphorylation of hydroxyl groups of seryl, threonyl or tyrosyl residues, methylation of the α -amino groups of lysine, arginine, and histidine side chains (T.E. Creighton, Proteins: Structure and Molecular Properties, W.H. Freeman & Co., San Francisco, pp. 79-86 [1983]), acetylation of the N-terminal amine, and amidation of any C-terminal carboxyl group. The molecules may further be covalently linked to nonproteinaceous polymers, e.g. polyethylene glycol, polypropylene glycol or polyoxyalkylenes, in the manner set forth in U.S.S.N. 07/275,296 or U.S. patents 4,640,835; 4,496,689; 4,301,144; 4,670,417; 4,791,192 or 4,179,337.

Derivatization with bifunctional agents is useful for preparing intramolecular aggregates of the O-fucosyltransferase with polypeptides as well as for cross-linking the O-fucosyltransferase polypeptide to a water insoluble support matrix or surface for use in assays or affinity purification. In addition, a study of interchain cross-links will provide direct information on conformational structure. Commonly used cross-linking agents include 1,1-bis(diazoacetyl)-2-phenylethane, glutaraldehyde, N-hydroxysuccinimide esters, homobifunctional imidoesters, and bifunctional maleimides. Derivatizing agents such as methyl-3-[(p-azidophenyl)dithio]propioimide yield photoactivatable intermediates which are capable of forming cross-links in the presence of light. Alternatively, reactive water insoluble matrices such as cyanogen bromide activated carbohydrates and the systems reactive substrates described in U.S. Patent Nos. 3,959,642; 3,969,287; 3,691,016; 4,195,128; 4,247,642; 4,229,537; 4,055,635; and 4,330,440 are employed for protein

immobilization and cross-linking.

Certain post-translational modifications are the result of the action of recombinant host cells on the expressed polypeptide. Glutaminyl and asparaginyl residues are frequently post-translationally deamidated to the corresponding glutamyl and aspartyl residues. Alternatively, these residues are deamidated under mildly acidic conditions. Either form of these residues falls within the scope of this invention.

Other post-translational modifications include hydroxylation of proline and lysine, phosphorylation of hydroxyl groups of seryl, threonyl or tyrosyl residues, methylation of the α -amino groups of lysine, arginine, and histidine side chains [T.E. Creighton, Proteins: Structure and Molecular Properties, W.H. Freeman & Co., San Francisco, pp. 79-86 (1983)].

Other derivatives comprise the novel polypeptides of this invention covalently bonded to a nonproteinaceous polymer. The nonproteinaceous polymer ordinarily is a hydrophilic synthetic polymer, i.e. a polymer not otherwise found in nature. However, polymers which exist in nature and are produced by recombinant or *in vitro* methods are useful, as are polymers which are isolated from nature. Hydrophilic polyvinyl polymers fall within the scope of this invention, e.g. polyvinylalcohol and polyvinylpyrrolidone. Particularly useful are polyvinylalkylene ethers such as polyethylene glycol, polypropylene glycol.

The O-fucosyltransferase polypeptides may be linked to various nonproteinaceous polymers, such as polyethylene glycol, polypropylene glycol or polyoxyalkylenes, in the manner set forth in U.S. Patent Nos. 4,640,835; 4,496,689; 4,301,144; 4,670,417; 4,791,192 or 4,179,337.

The O-fucosyltransferases may be entrapped in microcapsules prepared, for example, by coacervation techniques or by interfacial polymerization, in colloidal drug delivery systems (e.g. liposomes, albumin microspheres, microemulsions, nano-particles and nanocapsules), or in macroemulsions. Such techniques are disclosed in Remington's Pharmaceutical Sciences, 16th Edition, Osol, A., Ed. (1980).

VII. Glycosylation variants of the O-fucosyltransferase

The actual glycosylation pattern of the native O-fucosyltransferase is unknown, however, variants having glycosylation which differ from the actual native sequence are within the scope herein. For ease, changes in the glycosylation pattern of a native polypeptide are usually made at the DNA level, essentially using the techniques discussed hereinabove with respect to the amino acid sequence variants. Thus, glycosylation signals can be introduced into the DNA sequence of native O-fucosylation polypeptides.

Chemical or enzymatic coupling of glycosides to the O-fucosylation molecules of the molecules of the present invention may also be used to add carbohydrate substitutes. These procedures are advantageous in that they do not require production of the polypeptide that is capable of O-linked (or N-linked) glycosylation. Depending on the coupling mode used, the sugar(s) may be attached to (a) arginine and histidine, (b) free carboxyl groups, (c) free hydroxyl groups such as those of cysteine, (d) free sulfhydryl groups such as those of serine, threonine, or hydroxyproline, (e) aromatic residues such as those of phenylalanine, tyrosine, or tryptophan or (f) the amide group of glutamine. These methods are described in WO 87/05330 (published 11 September 1987), and in Aplin and Wriston, *CRC Crit. Rev. Biochem.*, pp. 259-306.

VIII. Anti-O-fucosyltransferase antibody preparation

(A) Polyclonal antibodies

Polyclonal antibodies to a O-fucosyltransferase molecule generally are raised in animals by multiple subcutaneous (sc) or intraperitoneal (ip) injections of the O-fucosyltransferase and an adjuvant. It may be useful to conjugate the O-fucosyltransferase or a fragment containing the target amino acid sequence to a protein that is immunogenic in the species to be immunized, e.g. keyhole limpet hemocyanin, serum albumin, bovine thyroglobulin, or soybean trypsin inhibitor using a bifunctional or derivatizing agent, for example maleimidobenzoyl sulfosuccinimide ester (conjugation through cysteine residues), N-hydroxysuccinimide (through lysine residues), glytaraldehyde, succinic anhydride, SOCl_2 , or $\text{R}'\text{N}=\text{C}=\text{NR}$, where R and R' are different alkyl groups.

Animals are immunized against the immunogenic conjugates or derivatives by combining 1 mg or 1 μg of conjugate (for rabbits or mice, respectively) with 3 volumes of Freud's complete adjuvant and injecting the solution intradermally at multiple sites. One month later the animals are boosted with 1/5 to 1/10 the original amount of conjugate in Freud's complete adjuvant by subcutaneous injection at multiple sites. 7 to 14 days later the animals are bled and the serum is assayed for anti-O-fucosyltransferase antibody titer. Animals are boosted until the titer plateaus. Preferably, the animal boosted with the conjugate of the same O-fucosyltransferase but conjugated to a different protein and/or through a different cross-linking reagent. Conjugates also can be made in recombinant cell culture as protein fusions. Also, aggregating agents such as alum are used to enhance the immune response.

(B) Monoclonal antibodies

Monoclonal antibodies are obtained from a population of substantially homogeneous antibodies, *i.e.*

the individual antibodies comprising the population are identical except for possible naturally-occurring mutations that may be present in minor amounts. Thus, the modifier "monoclonal" indicates the character of the antibody as not being a mixture of discrete antibodies.

For example, the anti-O-fucosyltransferase monoclonal antibodies of the invention may be made using the hybridoma method first described by Kohler & Milstein, *Nature* 256:495 (1975), or may be made by recombinant DNA methods [Cabilly, *et al.*, U.S. Pat. No. 4,816,567].

In the hybridoma method, a mouse or other appropriate host animal, such as hamster is immunized as hereinabove described to elicit lymphocytes that produce or are capable of producing antibodies that will specifically bind to the protein used for immunization. Alternatively, lymphocytes may be immunized in vitro. Lymphocytes then are fused with myeloma cells using a suitable fusing agent, such as polyethylene glycol, to form a hybridoma cell [Goding, Monoclonal Antibodies: Principles and Practice, pp.59-103 (Academic Press, 1986)].

The hybridoma cells thus prepared are seeded and grown in a suitable culture medium that preferably contains one or more substances that inhibit the growth or survival of the unfused, parental myeloma cells. For example, if the parental myeloma cells lack the enzyme hypoxanthine guanine phosphoribosyl transferase (HGPRT or HPRT), the culture medium for the hybridomas typically will include hypoxanthine, aminopterin, and thymidine (HAT medium), which substances prevent the growth of HGPRT-deficient cells.

Preferred myeloma cells are those that fuse efficiently, support stable high level expression of antibody by the selected antibody-producing cells, and are sensitive to a medium such as HAT medium. Among these, preferred myeloma cell lines are murine myeloma lines, such as those derived from MOPC-21 and MPC-11 mouse tumors available from the Salk Institute Cell Distribution Center, San Diego, California USA, and SP-2 cells available from the American Type Culture Collection, Rockville, Maryland USA. Human myeloma and mouse-human heteromyeloma cell lines also have been described for the production of human monoclonal antibodies [Kozbor, J. Immunol. 133:3001 (1984); Brodeur, *et al.*, Monoclonal Antibody Production Techniques and Applications, pp.51-63 (Marcel Dekker, Inc., New York, 1987)].

Culture medium in which hybridoma cells are growing is assayed for production of monoclonal antibodies directed against O-fucosyltransferase. Preferably, the binding specificity of monoclonal antibodies produced by hybridoma cells is determined by immunoprecipitation or by an in vitro binding assay, such as radioimmunoassay (RIA) or enzyme-linked immunoabsorbent assay (ELISA).

The binding affinity of the monoclonal antibody can, for example, be determined by the Scatchard analysis of Munson & Pollard, *Anal. Biochem.* 107:220 (1980).

After hybridoma cells are identified that produce antibodies of the desired specificity, affinity, and/or activity, the clones may be subcloned by limiting dilution procedures and grown by standard methods. Goding, Monoclonal Antibodies: Principles and Practice, pp.59-104 (Academic Press, 1986). Suitable culture media for this purpose include, for example, Dulbecco's Modified Eagle's Medium or RPMI-1640 medium. In addition, the hybridoma cells may be grown in vivo as ascites tumors in an animal.

The monoclonal antibodies secreted by the subclones are suitably separated from the culture medium, ascites fluid, or serum by conventional immunoglobulin purification procedures such as, for example, protein A-Sepharose, hydroxylapatite chromatography, gel electrophoresis, dialysis, or affinity chromatography.

DNA encoding the monoclonal antibodies of the invention is readily isolated and sequenced using conventional procedures (e.g., by using oligonucleotide probes that are capable of binding specifically to genes encoding the heavy and light chains of murine antibodies). The hybridoma cells of the invention serve as a preferred source of such DNA. Once isolated, the DNA may be placed into expression vectors, which are then transfected into host cells such as simian COS cells, Chinese hamster ovary (CHO) cells, or myeloma cells that do not otherwise produce immunoglobulin protein, to obtain the synthesis of monoclonal antibodies in the recombinant host cells. The DNA also may be modified, for example, by substituting the coding sequence for human heavy and light chain constant domains in place of the homologous murine sequences, Morrison, *et al.*, *Proc. Nat. Acad. Sci.* 81, 6851 (1984), or by covalently joining to the immunoglobulin coding sequence all or part of the coding sequence for a non-immunoglobulin polypeptide. In that manner, "chimeric" or "hybrid" antibodies are prepared that have the binding specificity of an anti-O-fucosyltransferase monoclonal antibody herein.

Typically such non-immunoglobulin polypeptides are substituted for the constant domains of an antibody of the invention, or they are substituted for the variable domains of one antigen-combining site of an antibody of the invention to create a chimeric bivalent antibody comprising one antigen-combining site having specificity for an O-fucosyltransferase and another antigen-combining site having specificity for a different antigen.

Chimeric or hybrid antibodies also may be prepared in vitro using known methods in synthetic protein

chemistry, including those involving crosslinking agents. For example, immunotoxins may be constructed using a disulfide exchange reaction or by forming a thioether bond. Examples of suitable reagents for this purpose include iminothiolate and methyl-4-mercaptobutyrimidate.

For diagnostic applications, the antibodies of the invention typically will be labeled with a detectable moiety. The detectable moiety can be any one which is capable of producing, either directly or indirectly, a detectable signal. For example, the detectable moiety may be a radioisotope, such as ^3H , ^{14}C , ^{32}P , ^{35}S , or ^{125}I , a fluorescent or chemiluminescent compound, such as fluorescein isothiocyanate, rhodamine, or luciferin; biotin; radioactive isotopic labels, such as, e.g., ^{125}I , ^{32}P , ^{14}C , or ^3H , or an enzyme, such as alkaline phosphatase, beta-galactosidase or horseradish peroxidase.

Any method known in the art for separately conjugating the antibody to the detectable moiety may be employed, including those methods described by Hunter, *et al.*, *Nature* 144:945 (1962); David, *et al.*, *Biochemistry* 13:1014 (1974); Pain, *et al.*, *J. Immunol. Meth.* 40:219 (1981); and Nygren, *J. Histochem. and Cytochem.* 30:407 (1982).

The antibodies of the present invention may be employed in any known assay method, such as competitive binding assays, direct and indirect sandwich assays, and immunoprecipitation assays. Zola, Monoclonal Antibodies: A Manual of Techniques, pp.147-158 (CRC Press, Inc., 1987).

Competitive binding assays rely on the ability of a labeled standard (which may be an O-fucosyltransferase polypeptide or an immunologically reactive portion thereof) to compete with the test sample analyte (O-fucosyltransferase) for binding with a limited amount of antibody. The amount of O-fucosyltransferase in the test sample is inversely proportional to the amount of standard that becomes bound to the antibodies. To facilitate determining the amount of standard that becomes bound, the antibodies generally are insolubilized before or after the competition, so that the standard and analyte that are bound to the antibodies may conveniently be separated from the standard and analyte which remain unbound.

Sandwich assays involve the use of two antibodies, each capable of binding to a different immunogenic portion, or epitope, of the protein to be detected. In a sandwich assay, the test sample analyte is bound by a first antibody which is immobilized on a solid support, and thereafter a second antibody binds to the analyte, thus forming an insoluble three part complex. David & Greene, U.S. Pat No. 4,376,110. The second antibody may itself be labeled with a detectable moiety (direct sandwich assays) or may be measured using an anti-immunoglobulin antibody that is labeled with a detectable moiety (indirect sandwich assay). For example,

one type of sandwich assay is an ELISA assay, in which case the detectable moiety is an enzyme.

(C) Humanized antibodies

Methods for humanizing non-human antibodies are well known in the art. Generally, a humanized antibody has one or more amino acid residues introduced into it from a source which is non-human. These non-human amino acid residues are often referred to as "import" residues, which are typically taken from an "import" variable domain. Humanization can be essentially performed following the method of Winter and co-workers [Jones *et al.*, *Nature* 321, 522-525 (1986); Riechmann *et al.*, *Nature* 332, 323-327 (1988); Verhoeven *et al.*, *Science* 239, 1534-1536 (1988)], by substituting rodent CDRs or CDR sequences for the corresponding sequences of a human antibody. Accordingly, such "humanized" antibodies are chimeric antibodies (Cabilly, *supra*), wherein substantially less than an intact human variable domain has been substituted by the corresponding sequence from a non-human species. In practice, humanized antibodies are typically human antibodies in which some CDR residues and possibly some FR residues are substituted by residues from analogous sites in rodent antibodies.

It is important that antibodies be humanized with retention of high affinity for the antigen and other favorable biological properties. To achieve this goal, according to a preferred method, humanized antibodies are prepared by a process of analysis of the parental sequences and various conceptual humanized products using three dimensional models of the parental and humanized sequences. Three dimensional immunoglobulin models are commonly available and are familiar to those skilled in the art. Computer programs are available which illustrate and display probable three-dimensional conformational structures of selected candidate immunoglobulin sequences. Inspection of these displays permits analysis of the likely role of the residues in the functioning of the candidate immunoglobulin sequence, i.e. the analysis of residues that influence the ability of the candidate immunoglobulin to bind its antigen. In this way, FR residues can be selected and combined from the consensus and import sequence so that the desired antibody characteristic, such as increased affinity for the target antigen(s), is achieved. In general, the CDR residues are directly and most substantially involved in influencing antigen binding. For further details see U.S. application Serial No. 07/934,373 filed 21 August 1992, which is a continuation-in-part of application Serial No. 07/715,272 filed 14 June 1991.

Alternatively, it is now possible to produce transgenic animals (e.g. mice) that are capable, upon immunization, of producing a full repertoire of human antibodies in the absence of endogenous immunoglobulin production. For example, it has been described that the homozygous deletion of the antibody heavy chain joining region (J_H) gene in chimeric and germ-line mutant mice results in complete inhibition of endogenous antibody production. Transfer of the human germ-line immunoglobulin gene array in such germ-

line mutant mice will result in the production of human antibodies upon antigen challenge. See, e.g., Jakobovits *et al.*, *Proc. Natl. Acad. Sci. USA* 90, 2551-255 (1993); Jakobovits *et al.*, *Nature* 362, 255-258 (1993).

(D) Bispecific antibodies

Bispecific antibodies are monoclonal, preferably human or humanized, antibodies that have binding specificities for at least two different antigens. In the present case, one of the binding specificities is for a O-fucosyltransferase, the other one is for any other antigen, and preferably for another receptor or receptor subunit. For example, bispecific antibodies specifically binding two different O-fucosyltransferases, are within the scope of the present invention.

Methods for making bispecific antibodies are known in the art. Traditionally, the recombinant production of bispecific antibodies is based on the coexpression of two immunoglobulin heavy chain-light chain pairs, where the two heavy chains have different specificities (Millstein and Cuello, *Nature* 305, 537-539 (1983)). Because of the random assortment of immunoglobulin heavy and light chains, these hybridomas (quadromas) produce a potential mixture of 10 different antibody molecules, of which only one has the correct bispecific structure. The purification of the correct molecule, which is usually done by affinity chromatography steps, is rather cumbersome, and the product yields are low. Similar procedures are disclosed in PCT application publication No. WO 93/08829 (published 13 May 1993), and in Traunecker *et al.*, *EMBO* 10, 3655-3659 (1991).

According to a different and more preferred approach, antibody variable domains with the desired binding specificities (antibody-antigen combining sites) are fused to immunoglobulin constant domain sequences. The fusion preferably is with an immunoglobulin heavy chain constant domain, comprising at least part of the hinge, and second and third constant regions of an immunoglobulin heavy chain (CH2 and CH3). It is preferred to have the first heavy chain constant region (CH1) containing the site necessary for light chain binding, present in at least one of the fusions. DNAs encoding the immunoglobulin heavy chain fusions and, if desired, the immunoglobulin light chain, are inserted into separate expression vectors, and are cotransfected into a suitable host organism. This provides for great flexibility in adjusting the mutual proportions of the three polypeptide fragments in embodiments when unequal ratios of the three polypeptide chains used in the construction provide the optimum yields. It is, however, possible to insert the coding sequences for two or all three polypeptide chains in one expression vector when the expression of at least two polypeptide chains in equal ratios results in high yields or when the ratios are of no particular significance. In a preferred embodiment of this approach, the bispecific antibodies are composed of a hybrid immunoglobulin heavy chain

with a first binding specificity in one arm, and a hybrid immunoglobulin heavy chain-light chain pair (providing a second binding specificity) in the other arm. It was found that this asymmetric structure facilitates the separation of the desired bispecific compound from unwanted immunoglobulin chain combinations, as the presence of an immunoglobulin light chain in only one half of the bispecific molecule provides for a facile way of separation. This approach is disclosed in copending application Serial No. 07/931,811 filed 17 August 1992.

For further details of generating bispecific antibodies see, for example, Suresh *et al.*, *Methods in Enzymology* 121, 210 (1986).

(5) Heteroconjugate antibodies

Heteroconjugate antibodies are also within the scope of the present invention. Heteroconjugate antibodies are composed of two covalently joined antibodies. Such antibodies have, for example, been proposed to target immune system cells to unwanted cells (U.S. Patent No. 4,676,980), and for treatment of HIV infection (PCT application publication Nos. WO 91/00360 and WO 92/200373; EP 03089). Heteroconjugate antibodies may be made using any convenient cross-linking methods. Suitable cross-linking agents are well known in the art, and are disclosed in U.S. Patent No. 4,676,980, along with a number of cross-linking techniques.

IX. METHODS OF USING O-FUCOSYLTRANSFERASE INHIBITORS

As reported previously, O-linked fucose has been found on a number of interesting biological molecules. Moreover it has been determined that glycosylations containing O-linked fucose are essential for proper activity of these biological molecules. More importantly, the absence of such O-linked fucose in these molecules has inhibited or lessened the efficacy of these molecules. For example, it has been reported in S.A. Rabbani *et al.*, *J. Biol. Chem.* (1992) 267:14151-56, that the binding of urokinase-type plasminogen activator (uPA) to its receptor (uPAR) is mediated by the EGF-domain. Furthermore, Rabbani *et al.* has reported that the fucosylated EGF domain of uPA was mitogenic for an osteosarcoma cell line, SaOS-2 and that, non-fucosylated EGF domain exhibited no mitogenic activity. This is particularly interesting, since non-fucosylated uPA, in a competitive inhibition assay with fucosylated uPA reduced the mitogenicity in the model.

The following proteins are known to have EGF domains similar to those capable of being glycosylated by the present O-fucosyltransferase: coagulation factor VII, coagulation factor VII(b), fibropellin C (III), scavenger receptor Cys-rich epidermal growth factor, notch 4, C-Serate -1, Motch B protein, neurogenic locus notch 3, notch 2, major fat-globule membrane protein/MGF-E8, coagulation factor IX, coagulation factor XII,

hepatocyte growth factor, agrin, alpha-2-macroglobulin receptor (low-density lipoprotein receptor-related protein 1 precursor), versican, chondroitin sulfate proteoglycan, plasminogen activator (uPA), teratocarcinoma-derived growth factor (Cripto growth factor), teratocarcinoma-derived growth factor-3 (Cripto-3 growth factor), Motch A, milk fat globule-EGF factor VIII (MFGM), fibropellin Ia, fibropellin Ib, proteoglycan PG-M(V3), fibropellin I, C-serrate-2, transmembrane protein jagged, transmembrane protein jagged-1, versican v2, neurogenic locus notch homolog 4 (transforming protein int-3), crumbs, tie receptor tyrosine kinase, fibroblast growth factor receptor ligand, fetal antigen 1, preadipocyte factor 1, delta-like dlk protein, stromal cell derived protein-1, deltaD transmembrane protein, x-Delta-1, agrin-related protein 1, neurogenic protein Delta precursor, prepromultimerin, serrate protein, slit protein 2, slit, G-protein coupled receptors, EGF repeat transmembrane protein and neurogenic locus notch 1.

Methods for preparing O-fucosyltransferase inhibitors are similar to those as is described for the preparation of O-fucosyltransferase variants under section B of Part II: Recombinant Production of O-Fucosyltransferase.

Therapeutic formulations of the polypeptide or antibody are prepared for storage as lyophilized formulations or aqueous solutions by mixing the polypeptide having the desired degree of purity with optional "pharmaceutically-acceptable" carriers, excipients or stabilizers typically employed in the art (all of which are termed "excipients"). For example, buffering agents, stabilizing agents, preservatives, isotonicifiers, non-ionic detergents, antioxidants and other miscellaneous additives. (See *Remington's Pharmaceutical Sciences*, 16th edition, A. Osol, Ed. (1980)). Such additives must be nontoxic to the recipients at the dosages and concentrations employed.

Buffering agents help to maintain the pH in the range which approximates physiological conditions. They are preferably present at concentration ranging from about 2mM to about 50 mM. Suitable buffering agents for use with the present invention include both organic and inorganic acids and salts thereof such as citrate buffers (e.g., monosodium citrate-disodium citrate mixture, citric acid-trisodium citrate mixture, citric acid-monosodium citrate mixture, etc.), succinate buffers (e.g., succinic acid-monosodium succinate mixture, succinic acid-sodium hydroxide mixture, succinic acid-disodium succinate mixture, etc.), tartrate buffers (e.g., tartaric acid-sodium tartrate mixture, tartaric acid-potassium tartrate mixture, tartaric acid-sodium hydroxide mixture, etc.), fumarate buffers (e.g., fumaric acid-monosodium fumarate mixture, etc.), fumarate buffers (e.g., fumaric acid-monosodium fumarate mixture, fumaric acid-disodium fumarate mixture, monosodium fumarate-disodium fumarate mixture, etc.), gluconate buffers (e.g., gluconic acid-sodium glyconate mixture, gluconic acid-sodium hydroxide mixture, gluconic acid-potassium glyconate mixture, etc.), oxalate buffer (e.g., oxalic

acid-sodium oxalate mixture, oxalic acid-sodium hydroxide mixture, oxalic acid-potassium oxalate mixture, etc.), lactate buffers (e.g., lactic acid-sodium lactate mixture, lactic acid-sodium hydroxide mixture, lactic acid-potassium lactate mixture, etc.) and acetate buffers (e.g., acetic acid-sodium acetate mixture, acetic acid-sodium hydroxide mixture, etc.). Additionally, there may be mentioned phosphate buffers, histidine buffers and trimethylamine salts such as Tris.

Preservatives are added to retard microbial growth, and are added in amounts ranging from 0.2% - 1% (w/v). Suitable preservatives for use with the present invention include phenol, benzyl alcohol, *meta*-cresol, methyl paraben, propyl paraben, octadecyldimethylbenzyl ammonium chloride, benzalconium halides (e.g., chloride, bromide, iodide), hexamethonium chloride, alkyl parabens such as methyl or propyl paraben, catechol, resorcinol, cyclohexanol, and 3-pentanol.

Isotonicifiers sometimes known as "stabilizers" are present to ensure isotonicity of liquid compositions of the present invention and include polyhydric sugar alcohols, preferably trihydric or higher sugar alcohols, such as glycerin, erythritol, arabitol, xylitol, sorbitol and mannitol. Polyhydric alcohols can be present in an amount between 0.1% to 25% by weight, preferably 1% to 5% taking into account the relative amounts of the other ingredients.

Stabilizers refer to a broad category of excipients which can range in function from a bulking agent to an additive which solubilizes the therapeutic agent or helps to prevent denaturation or adherence to the container wall. Typical stabilizers can be polyhydric sugar alcohols (enumerated above); amino acids such as arginine, lysine, glycine, glutamine, asparagine, histidine, alanine, ornithine, L-leucine, 2-phenylalanine, glutamic acid, threonine, etc., organic sugars or sugar alcohols, such as lactose, trehalose, stachyose, mannitol, sorbitol, xylitol, ribitol, myoinositol, galactitol, glycerol and the like, including cyclitols such as inositol; polyethylene glycol; amino acid polymers; sulfur containing reducing agents, such as urea, glutathione, thiocetic acid, sodium thioglycolate, thioglycerol, α -monothioglycerol and sodium thio sulfate; low molecular weight polypeptides (i.e. < 10 residues); proteins such as human serum albumin, bovine serum albumin, gelatin or immunoglobulins; hydrophylic polymers, such as polyvinylpyrrolidone monosaccharides, such as xylose, mannose, fructose, glucose; disaccharides such as lactose, maltose, sucrose and trisaccharides such as raffinose; polysaccharides such as dextran. Stabilizers are present in the range from 0.1 to 10,000 weights per part of weight active protein.

Non-ionic surfactants or detergents (also known as "wetting agents") are present to help solubilize the therapeutic agent as well as to protect the therapeutic protein against agitation-induced aggregation, which also

permits the formulation to be exposed to shear surface stressed without causing denaturation of the protein. Suitable non-ionic surfactants include polysorbates (20, 80, etc.), polyoxamers (184, 188 etc.), Pluronic[®] polyols, polyoxyethylene sorbitan monoethers (Tween[®]-20, Tween[®]-80, etc.). Non-ionic surfactants are present in a range of about 0.05 mg/ml to about 1.0 mg/ml, preferably about 0.07 mg/ml to about 0.2 mg/ml.

Additional miscellaneous excipients include bulking agents, (e.g. starch), chelating agents (e.g. EDTA), antioxidants (e.g., ascorbic acid, methionine, vitamin E), and cosolvents.

The formulation herein may also contain more than one active compound as necessary for the particular indication being treated, preferably those with complementary activities that do not adversely affect each other. For example, it may be desirable to further provide an immunosuppressive agent. Such molecules are suitably present in combination in amounts that are effective for the purpose intended.

The active ingredients may also be entrapped in microcapsule prepared, for example, by coascervation techniques or by interfacial polymerization, for example, hydroxymethylcellulose or gelatin-microcapsule and poly-(methylmethacrylate) microcapsule, respectively, in colloidal drug delivery systems (for example, liposomes, albumin microppheres, microemulsions, nano-particles and nanocapsules) or in macroemulsions. Such techniques are disclosed in *Remington's Pharmaceutical Sciences*, 16th edition, A. Osal, Ed. (1980).

The formulations to be used for in vivo administration must be sterile. This is readily accomplished, for example, by filtration through sterile filtration membranes.

Sustained-release preparations may be prepared. Suitable examples of sustained-release preparations include semi-permeable matrices of solid hydrophobic polymers containing the antibody mutant, which matrices are in the form of shaped articles, e.g., films, or microcapsules. Examples of sustained-release matrices include polyesters, hydrogels (for example, poly(2-hydroxyethyl-methacrylate), or poly(vinylalcohol)), polylactides (U.S. Pat. No.3,773,919), copolymers of L-glutamic acid and ethyl-L-glutamate, non-degradable ethylene-vinyl acetate, degradable lactic acid-glycolic acid copolymers such as the LUPRON DEPOT[™] (injectable microspheres composed of lactic acid-glycolic acid copolymer and leuprolide acetate), and poly-D- (-)-3-hydroxybutyric acid. While polymers such as ethylene-vinyl acetate and lactic acid-glycolic acid enable release of molecules for over 100 days, certain hydrogels release proteins for shorter time periods. When encapsulated antibodies remain in the body for a long time, they may denature or aggregate as a result of exposure to moisture at 37°C, resulting in a loss of biological activity and possible changes in immunogenicity. Rational strategies can be devised for stabilization depending on the mechanism involved. For example, if the aggregation mechanism is discovered to be intermolecular S-S bond formation through thio-

disulfide interchange, stabilization may be achieved by modifying sulfhydryl residues, lyophilizing from acidic solutions, controlling moisture content, using appropriate additives, and developing specific polymer matrix compositions.

The amount of therapeutic polypeptide, antibody or fragment thereof which will be effective in the treatment of a particular disorder or condition will depend on the nature of the disorder or condition, and can be determined by standard clinical techniques. Where possible, it is desirable to determine the dose-response curve and the pharmaceutical compositions of the invention first in vitro, and then in useful animal model systems prior to testing in humans. However, based on common knowledge of the art, a pharmaceutical composition effective in promoting the survival of sensory neurons may provide a local therapeutic agent concentration of between about 5 and 20 ng/ml, and, preferably, between about 10 and 20 ng/ml. In an additional specific embodiment of the invention, a pharmaceutical composition effective in promoting the growth and survival of retinal neurons may provide a local therapeutic agent concentration of between about 10 ng/ml and 100 ng/ml.

In a preferred embodiment, an aqueous solution of therapeutic polypeptide, antibody or fragment thereof is administered by subcutaneous injection. Each dose may range from about 0.5 μ g to about 50 μ g per kilogram of body weight, or more preferably, from about 3 μ g to about 30 μ g per kilogram body weight.

The dosing schedule for subcutaneous administration may vary from once a week to daily depending on a number of clinical factors, including the type of disease, severity of disease, and the subject's sensitivity to the therapeutic agent.

The following examples are offered by way of illustration and not by way of limitation. The disclosures of all citations in the specification are expressly incorporated herein by reference.

EXAMPLES

EXAMPLE I

Sequence analysis

Amino terminal sequences of the purified O-fucosyltransferase from CHO cells was obtained using an automated gas-phase sequencer. The protein (2 µg) was subjected to analysis for 61 cycles. The sequence obtained was the following:

RLAGSWDLAGYLLYXPXMGRFGNQADHFLGSLAFKLVVTLAVPPWIEYQHHKPPFTNLH
[SEQ ID NO:3]

Cycles that yielded uncertain residues were marked as X. They are probably glycosylation sites or cysteine residues forming disulfide bonds with other parts of the protein. A search on GenBank with the above sequence found two homologous genes of unknown function from human and *C. elegans* (Fig. 9). The human sequence, KIAA0180, is 5009 bp partial cDNA coding for protein of unknown function from myeloblast cell line KG-1. The similarity between Applicants' CHO cell and the published human sequence is around 95% at the region they overlap (39 amino acid residues at carboxyl side of the CHO cell sequence). The polypeptide from *C. elegans* was generated by computer analysis of *C. elegans* genomic sequence, CELC15C7_5. The entire 61 residues of Applicants' CHO cell sequence has a 37% similarity with the *C. elegans* sequence. However, if only the C-terminal 43 amino acid residues of the CHO cell sequence is compared, the similarity increases to 76%. A realistic comparison between the CHO cell and published human sequences is not possible due to the incomplete sequence information available on the human sequence. The similarity between the human and *C. elegans* sequences is about 40%.

Northern blot analysis

Oligonucleotide probes were made by filling two partially complement oligonucleotides from human KIAA0180 (sequences 16-55 and 80-41). These sequences also overlapped with the CHO cell polypeptide sequence as is indicated in Fig. 11. The two northern probes corresponded to the following sequences:

5'-CTTCT TGGGCTCTCT GGCATTTGCA AAGCTGCTAA ACCGT-3' [SEQ ID NO:10]
[SEQ ID NO:11] 3'-TTCGACGATT TGGCATGGAA CCGACAGGGA GGAACCTAAC-5'

The human multi-tissue RNA blot was purchased from Clontech and the experiment was carried out according to the vendor's instructions. The blot resulted in two bands of about 5 and 5.5 kb, respectively, which were present in heart, placenta, liver, muscle and pancreas, but not lung, kidney and brain (See Fig. 10). The sequences of the probes were taken from human KIAA0180 position 16-80, the region which matched with the CHO cell O-fucosyltransferase N-terminal polypeptide sequence of Figure 11.

Isolation of cDNA clones

The primers for the polymerase chain reaction (PCR) were taken from KIAA0180 and corresponded to k16-55 and k110-1071. The primers corresponded to the following sequences:

5'-CTTCT TGGGCTCTCT GGCATTGCA AAGCTGCTAA ACCGT-3' [SEQ ID NO:12]

3'-TCCCTGGGGA GTTCCTCCCT CTGCGAGGTA-5' [SEQ ID NO:13]

The predicted product was about 1.1 kb (See Fig. 11). Probes were then made by the random priming method using the PCR product as the template.

Human heart cDNA library was purchased from Clontech. The screening was carried out according to the product manual. After the screening of one million recombinant clones, 31 positive clones were identified, of which 20 were subjected to two more screenings for confirmation. Recombinant lambda DNA from the isolated clones was digested with EcoR1 and subjected to southern blotting (Ausubel et al, Ch. 2, supra), using the same probe as for the northern blot described above, which resulted in 8 clones possibly containing the coding sequence for O-fucosyltransferase.

Subcloning and DNA sequencing:

The positive EcoR1 fragments, as identified by the southern blot, were purified using a Qiagen extraction kit from agarose gel and subcloned into pBluescriptII SK+ plasmid (Stratagene). The plasmid DNA was prepared using the Qiagen Maxiprep kit and used for DNA sequencing. DNA sequencing was carried out on a ABI 370 automated DNA sequencer, which identified that seven of the eight clones contained the KIAA0180 sequence. A compiled sequence was obtained from the data which contained both the KIAA0180 first EcoR1 fragment and the N-terminal polypeptide sequence of O-fucosyltransferase from the CHO cells (Figure 12A). Although the translated polypeptide starts with a Met residue, the exact N-terminal residues are yet to be determined. The clones that extended beyond the 5' methionine residue all had different sequences, possibly due to a cloning artifact introduced by the GC rich region. The polypeptide from the obtained sequence as indicated in Fig. 12B most likely represents the sequence of active human O-fucosyltransferase, since the N-terminal sequence of active CHO enzyme started at the same position, although with arginine instead of methionine. The alignment of human and CHO cell sequences is also shown in Figure 12B.

Expression

Baculovirus expression system was used to express the protein in Sf9 insect cells. A modified form of plasmid pVL1392 was used as the vector, as indicated by Figure 13. This plasmid was particularly designed for expression in baculovirus-insect expression systems. It consisted of an artificial signal peptide designed for secretion, a six-histidine tag for purification and the putative human O-fucosyltransferase described above. Transfection was carried out with a BaculoGold expression kit (Pharmingen). Five (5) recombinant virus

clones were plaque-purified three times. Virus stocks of 10^8 pfu/ml were prepared by repeated amplification. Expression was done transfecting 5×10^8 pfu recombinant viruses to 2×10^7 Sf9 cells. The O-fucosyltransferase activity assay of the Sf9 culture media after the virus infection showed that four (4) of the five clones expressed secretory O-fucosyltransferase and cultures infected with the fifth virus and uninfected Sf9 cells had no enzyme activity (Fig. 14).

Both culture media and cells were collected 72 hours after infection and recombinant O-fucosyltransferase was purified using Ni^{2+} -NTA agarose according to the manufacturer's directions. The protein purified from the cell lysate gave a single band of 43 kd on silver stained SDS-PAGE (Fig. 15), which agreed with the predicted size of the molecule. The amino terminal sequence, as determined by N-terminal sequence analysis was obtained using gas-phase sequencing and confirmed that the expressed protein was recombinant and not an Sf9 cell endogenous enzyme. The N-terminal sequence was determined to be the following:

RSHHHHHHMPAGSWDPAGYLLYXPXMGR [SEQ ID NO:14]

Example 2

Fucosyltransferase Assay

A reaction volume of 50 μl contained the following ingredient: 0.1 M imidazole-HCl, pH 7.0; 50 mM MnCl_2 ; 0.1 mM GDP- ^{14}C -Fucose (4000-8000 cpm/nmol), 20 μM recombinant human Factor VII EGF-1 domain and about 0.01-0.1 milliunit of enzyme activity. The mixture was incubated at 37°C for 10-20 minutes. The reaction was stopped by placing the mixture on ice, then diluting with 950 μl of 0.25 M EDTA, pH 8.0. Separation of incorporated fucose from GDP-fucose, fucose-phosphate and free fucose was carried out by passing the solution through a C18 cartridge (Alltech, Extract Clean, C18, 200 mg). The cartridge was washed with 5 ml of H_2O , and the product was then eluted with 3 ml of 80% acetonitrile containing 0.052% TFA. The eluant was mixed with 10 ml Aquasol II (NEN/Du Pont) and counted using a liquid scintillation counter.

Recombinant human factor VII and IX EGF domains and mutants

The construction of human Factor IX EGF domain and its mutant genes were the same as for Factor VII EGF domain. A recombinant form of the first EGF domain from human factor VII was produced in *E. coli*. The sequences of the EGF domains was taken from residue 45-87 of the mature protein, with six histidine residues attached at the C-terminus, followed by three residues from the cloning vector. The construct included the following primary sequence:

TVDGDQCESNPCLNGGSCKDDINSYECWCPFGFEGKNCELDVTHHHHHHGSA

[Seq. ID. No. 15]

The mutants were constructed using the same oligonucleotide cassette with mutated sequences

according to the method of cassette mutagenesis, Wells et al., *Gene* **34**, 315 (1985). The expression was carried out on a 1 liter scale. The recombinant EFG domains were purified from periplasmic shokates using Ni^{2+} -NTA agarose (Qiagen) according to the manufacturer's instruction for non-denaturing purification. For 1 liter of culture fluid, 0.5 ml of resin was used and the eluant was then concentrated in Centricon-3 to about 200 μl and used in subsequent steps.

Example 3

Purification of O-fucosyltransferase from CHO cell extract

Purification of O-fucosyltransferase: Most of the enzyme activity is recoverable in the soluble fraction of the cell lysate. While the activity should not bind to a DE-52 anion exchange column, it should be found to be quantitatively retained on Affi-Gel blue resin. We have discovered further that this enzyme bears a high affinity towards both its acceptor substrate, the recombinant EGF domain, and a donor substrate analog, GDP-hexanolamine. As a result, affinity resins with these two molecules as ligands were made, which is a key purification step. The enzyme was purified 5000-fold from the cell paste with 20% yield, as measured by activity. This information is reported in Table 1.

Step 1: Preparation of CHO cell extract:

Since O-fucosyltransferase exhibits properties similar to those of other membrane-bound proteins, it is likely to have also a stem region very susceptible to proteolysis. In order to avoid the processing of membrane particles, protease inhibitors should be omitted during the initial homogenate preparation. The frozen CHO cell paste was thawed at room temperature and kept cold at 4°C afterward during the entire procedure. Low ionic strength buffer was used during homogenization to help break the cells, and the addition of DNase I to the homogenate reduced the viscosity and facilitated the subsequent chromatography steps. As indicated in Table I, most of the activity was recovered after the first step, which achieved a 2.2-fold purification.

Frozen CHO cell paste (100 grams) was thawed at room temperature and kept cold on ice. The cells were homogenized by sonication in 300 ml buffer of 20 mM imidazole-HCl, pH 7.0 and 25 mM NaCl with three 30 second bursts (Virsonic 550, at 20% output with 1/2 inch probe). DNaseI (2 mg/ml, 1 ml) and 1 M MgCl_2 (0.4 ml) were added to the homogenate, which was then centrifuged at 10,000 x g (Sorvell RC-5, GSA rotor) for 45 minutes. The supernatant (355 ml) was retained for further purification.

Step 2: DE-52 and Affi-Gel Blue Chromatography:

Since the enzyme flowed through the DE-52 column and bound to the Affi-Gel Blue, the two columns were connected for loading and initial washing steps. At point A as indicated in Figure 2, the DE-52 column was detached from the Affi-Gel Blue column. Some loosely bound protein was washed off upon increase of salt concentration (125 mM NaCl). At point B, as indicated in Figure 2, the enzyme was then eluted with 1 M NaCl. The application of a NaCl gradient here did not improve the purification. In Figure 2, the amount of protein not associated with the enzyme activity was relatively low because a significant portion of that bound to the DE-52 column and was not shown in the chromatogram. The combined purification for the two columns was 7.3 fold with 70% yield. The total volume of the preparation was reduced from 350 to 40 ml.

Two columns, one DE-52 (2.5 x 3.0 cm) and the other Affi-Gel Blue (2.5 x 15 cm) were connected and equilibrated with the same buffer used for homogenization. The supernatant from the CHO cell extract step was loaded onto the DE-52 column (1 ml/min.) and the columns were washed with the same buffer. The DE-52 column was then detached from the Affi-Gel Blue column. The latter was washed with 200 ml buffer of 25 mM imidazole-HCl, pH 7.0 and 125 mM NaCl and followed by 400 ml high salt (25 mM imidazole-HCl, pH 7.0, 1 M NaCl) elution. The eluted fraction containing enzyme activity were pooled and dialyzed against the buffer of 25 mM Tris-HCl, pH 8.0, 25 mM NaCl and 25% (w/v) glycerol. The final volume was 40 ml.

Step 3: FVII-EGF-H6-Ni²⁺-NTA-Agarose (Acceptor substrate)

The preferable acceptor analog resin for use with the present invention is Factor VII-EGF-his₆ and Ni²⁺-NTA agarose. The use of Ni²⁺-NTA agarose has several advantages over conventional covalent cross-linking resins. First, the EGF ligand is attached to the resin in a defined orientation, according to the position of polyhistidine sequence. The EGF ligand may be prepared as described in Example 2. The O-fucosyltransferase enzyme bound to the resin better when the polyhistidine tag was at the carboxyl-terminus of the EGF domain rather than at its amino-terminus, hence the former was used for the purification. Second, the binding of the polyhistidine tag to Ni²⁺-NTA resin was stable under most conditions used for protein purification. The coupling of EGF to Ni²⁺-NTA-Agarose was almost quantitative and the resin was very stable. It is possible to elute the protein with the ligand together under very mild conditions, such as imidazole or EDTA. The coupling of the recombinant EGF to Ni²⁺-NTA agarose is very simple and fast, and is preferably carried out by mixing the resin and ligand in Tris buffer. It is further possible to use the recombinant EGF without the initial purification on a nickel column.

We have observed no leakage of recombinant EGF domain even after extensive washing. As shown in Figure 3, the binding of the enzyme to the resin was quantitative. At point A in Figure 3, the column was washed with

buffer containing 0.5 M NaCl, and a large amount of non-specifically bound protein was eluted. The binding of enzyme to the EGF domain was sufficiently strong so as to withstand a washing with 2M NaCl.

Since denaturation of the enzyme was possible, and linkage to the Ni^{2+} -NTA resin was non-covalent, the enzyme was recovered by first dissociating the EGF domain from the resin. At Point B, as indicated in Fig. 3, the column was washed with buffer containing 25 mM imidazole, and more non-specifically bound protein came off. At point C, as indicated in Fig. 3, 0.3 M imidazole solution was used to elute the polyhistidine tagged EGF domain together with the enzyme. The step purification was actually significantly higher than the 16-fold indicated in Table I because there was almost 6 mg of recombinant Factor VII EGF domain present in the eluate.

The affinity resin with acceptor substrate as ligand was made by mixing 6 mg of FVII-EGF- H_6 with 10 ml Ni^{2+} -NTA-Agarose resin in 0.1 M Tris-HCl, pH 8.0 for 4 hours at 4°C. The resin was then packed into a column (1.5 x 6.0 cm) and washed with 40 ml 0.1 M Tris-HCl, pH 8.0, followed by another wash of 30 ml 0.1 M Tris-HCl, 0.5 M NaCl. It was then equilibrated with the same buffer used for dialysis in the DE-52 and Affi-Gel Blue chromatography step.

The dialyzed sample was supplemented with 1 mM MnCl_2 and 0.1 mM GDP and loaded onto the affinity column at a flow rate of 0.5 ml/min. followed by 40 ml of the same buffer (with 1 mM MnCl_2 and 0.2 mM GDP). The column was then washed with 45 ml of the same buffer containing 0.5 M NaCl and 45 ml of 25 mM imidazole-HCl, pH 7.0, 25 mM NaCl and 25% (w/v) glycerol, respectively. The enzyme was then eluted off the column with 90 ml of 0.3 M imidazole-HCl, pH 7.0, 25% (w/v) glycerol. The fractions containing activity were pooled and dialyzed against 25 mM imidazole-HCl, pH 7.0, 25 mM NaCl, 25% (w/v) glycerol.

Step 4: GDP-Hexanolamine Agarose (Donor substrate)

GDP-hexanolamine-agarose has been used extensively in purification of many fucosyltransferases. Beyer et al., *J. Biol. Chem.* **255** (11), 5364-5372 (1980). O-fucosyltransferase also binds to this resin. However, as indicated in Fig. 4, at least half of the total amount of the enzyme flowed through the column when the sample was loaded onto column containing GDP-hexanolamine-agarose. At point A, as indicated in Fig. 4, the column was washed with buffer containing 125 mM NaCl, resulting in the elution of some non-specifically bound protein. After this point, a GDP gradient (0-2 mM) was used for specific elution of the enzyme. The fractions collected from this gradient contained a very limited amount of protein, as indicated by Fig. 5. In Fig. 5, a SDS-PAGE gel overstained with silver staining only a single band of 44 KD was visible. The variation of the band intensity also reflects the enzyme activity amongst the different fractions.

The affinity resin with donor substrate analog as ligand was made by coupling GDP-Hexanolamine (30 μ mol) to CNBr activated Sepharose 4B resin (10 ml, Pharmacia) according to the manufacturer's instructions). The resin was then packed in a column (i.d. 1.5 cm) and equilibrated with the same buffer used for preparation of the acceptor substrate column.

The dialyzed sample (13 ml) was supplemented with 5 mM $MnCl_2$ and loaded onto the column at 5 ml/hr. The column was then washed with 30 ml of 25 mM imidazole-HCl, pH 7.0, 25 mM NaCl, 5 mM $MnCl_2$ and 25% (w/v) glycerol, followed by 45 ml of the same buffer with 125 mM NaCl and then another 10 ml of the buffer containing 24 mM NaCl. The elution was carried out by using a linear gradient from 0-2 mM GDP, which started with 100% of 25 mM imidazole-HCl, pH 7.0, 25 mM NaCl, 5 mM $MnCl_2$, 25% (w/v) glycerol and finished with 100% of the same buffer with 2 mM GDP in a total volume of 50 ml. The column was washed with another 40 ml of the latter buffer. Fractions containing activity were first examined by silver stained SDS-PAGE and those with only a single band were pooled. Glycerol was then added to a final concentration of 50% (w/v) for storage at $-20^\circ C$.

The results of the purification are reported in Table 1 which indicates the results of one preparation of enzyme from 100 grams of CHO cell paste. Chromatograms of steps 2-4 are reported in Figures 2-4, respectively.

Table 1
Summary of the O-fucosyltransferase purification

Preparation	Total protein (mg)	Total volume (ml)	Total activity (units)	Specific activity (units/mg)	Step purification (fold)	Total purification (fold)	Step yield (%)	yield (%)
Homogenate	5735.8	400	0.911	0.00016	-	-	-	-
1. Supernatant	2238.6	350	0.785	0.00035	2.2	2.2	86.2	86.2
2. DE-52/Affi-Gel Blue	215.4	40	0.550	0.0026	7.3	16.1	71.1	60.4
3. FVIIIEGF-Ni ²⁺ -NTA-Agarose	9.81	13	0.401	0.041	16.0	256	72.9	44.1
4. GDP-	0.237	21	0.186	0.784	19.2	4937	46.4	20.4

Preparation	Total protein (mg)	Total volume (ml)	Total activity (units)	Specific activity (units/mg)	Step purification (fold)	Total purification (fold)	Step yield (%)	yield (%)
Hexanolamine-Agarose								

Example 3

Glycosidase digestion of the purified O-fucosyltransferase

1. PNGase F digestion

Pure protein in storage buffer (50 μ l) was first precipitated with 250 μ l acetone at -20°C and was then spun in a microcentrifuge for 15 minutes. The pellet was washed with 200 μ l acetone and air dried. The protein was then redissolved in 10 μ l of 0.5% SDS, 10 mM β -mercaptoethanol and 0.15 M Tris-HCl, pH 8.0 and heated at 100°C for 3 minutes. The digestion was carried out by adding 0.5 units of PNGase F in 20 μ l of 2% NP-40, 30 mM EDTA, pH 8.0 and the solution was incubated at 37°C overnight. The digested sample (10 μ l) was directly analyzed on SDS-PAGE.

2. Endo H digestion

The protein was denatured as described above. The digestion was carried out with 1 mU of the glycosidase in 30 μ l of 50 mM sodium citrate, pH 5.5, 2 mM PMSF, 0.25% NP-40 at 37°C for 4.5 hours. An aliquot (10 μ l) of the sample was analyzed on SDS-PAGE to determine the progress of the digestion.

Reverse phase HPLC and electrospray mass spectrometry

LC-MS analyses were performed on a PE/Sciex AP-300 triple quadrupole mass spectrometer interacted with a Hewlett-Packard 1090 liquid chromatograph system. Separations were carried out on a C-18 column (2.1 x 250 mm, Vydac), running a water/acetonitrile/TFA gradient at 0.2 ml/min. Buffer A contained 0.06% TFA and water, Buffer B was 0.052% TFA and 80% acetonitrile. The gradient had the following steps: 0-1 min., 2-10% B; 1-5 min., 10-25% B; 5-25 min., 25-35% B; 25-30 min., 35-98% B. The column effluent was monitored at 214 nm for protein and subsequently introduced into the mass spectrometer through a 1:5 splitter in front of a regular ion sprayer. The orifice potential was set at 50V and the ion-spray potential was at 4700 V. Mass scan was performed from 400-2500 m/z with step size of 0.5 amu and dwell time 0.1 ms. The data were analyzed

using a BioMultiView 1.2.

Characterizations

1. Glycosidase digestion:

Many glycosyltransferases are glycoproteins themselves and contain various types and amounts of oligosaccharides. Moreover, the majority of these glycosyltransferases reside in the endoplasmic reticulum or Golgi apparatus. The nature of glycosylation of the purified O-fucosyltransferase was examined using two endoglycosidases, PNGase F and Endo H. Figure 6 indicates that after PNGase digestion, the molecular weight of the protein reduced about 4 kd to 40 kd (Lane 2), suggesting the presence of an N-linked oligosaccharide. The results also indicate that more than one high mannose type oligosaccharide was present on the enzyme.

2. Acceptor substrate specificity:

As described previously, all the O-fucosylation on EGF domains occur within the putative consensus sequence CXXGGS/TC. In order to prove whether or not the two glycine residues are required for O-fucosylation, human factor IX EGF domain mutants were constructed as shown in Table II. Three mutants were constructed using alanine to replace either of the two or both glycine residues and tested as acceptor substrate for the purified O-fucosyltransferase. Assays using the four recombinant EGF domains all gave positive counts. It appeared that the two glycine residues were not absolutely required for activity.

Table II. Human Factor IX EGF domain mutants

Sequence name	Sequence	Mol. Wt.	Fucose (cpm)
EGF.AA	-CLNAASC-	5816.3	1818
EGF.AG	-CLNAGSC-	5802.3	4585
EGF.GA	-CLNGASC-	5802.3	6480
EGF (wild type)	-CLNGGSC-	5788.2	12062

Analysis of the recombinant factor IX EGF domains using reverse phase HPLC revealed that upon the change of glycine to alanine, the mutant EGF domains exhibited multiple peaks on the chromatograms whereas the wildtype had only one peak (Figure 7). Further characterizations of the different peaks by electrospray mass spectrometry indicated that all the peaks from one mutant had the same molecular weight, suggesting that the multiple peaks represented differently folded species of mutant EGF domains. The analysis also leads to the conclusion that the change of either glycine residue had a significant effect upon the folding of the EGF

domain.

In order to determine if all the different forms of the mutants served as substrate for the O-fucosyltransferase, reverse-phase HPLC online with electrospray mass spectrometry was used to analyze the product of the fucosylation reaction. Shown in Figure 8 is the experiment using the mutant ala-ala. Analysis of the other tested mutants gave similar results. After the fucosylation reaction, the molecular weight of three of the four peaks (30.4) had a different molecular weight (5964), which was 146 more than the other peaks (5817) and the corresponding peak before the fucosylation reaction. These results indicate that only one of the four differently folded species served as an acceptor substrate for the O-fucosyltransferase. Although the two glycine residues were not absolutely required for activity, their presence was important for proper folding of the EGF domain, hence the wild type EGF domain was a better substrate than the mutants. The enzyme O-fucosyltransferase required its substrate in order to have the proper three dimensional structure in order to function properly.